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Ecology, Pathology, and Management of Port-Orford-Cedar *(Chamaecyparislawsoniana)*

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Abstract

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Information about the biology, diseases, and management of Port-Orford-cedar was collected from the literature, from unpublished research data of the authors and the USDA Forest Service, conversations with personnel involved in all facets of Port-Orford-cedar management, and visits to stands throughout the range of the species. Information is summarized and presented regarding species characteristics, distribution, environment, vegetation, autecology, usage, past management, and the biology and effects of the most important pathogen. Recommendations for managing the species in the presence of this pathogen, *Phytophthora* lateralis, were developed. Presence of this introduced pathogen will complicate the management of Port-Orford-cedar and somewhat reduce the area where it can be grown, but production of future crops of cedar should be possible given careful, consistent application of the guidelines presented.

Keywords: Autecology, silvical characteristics, silviculture, root rot, ornamental trees, Port-Orford-cedar.

Summary

Port-Orford-cedar grows naturally in a limited area in coastal northern California and southern Oregon. Distribution is spotty and limited to those sites with the most consistent summer moisture. It grows on sites with a wide variety of soil types (often poor), with a wide range of temperatures, and with many other tree species.

Port-Orford-cedar grows, and can dominate some stands, in all vegetation zones within its range from the coastal Sitka spruce-western hemlock forests to high-elevation true fir forests and open pine-dominated forests on ultramafic soils in the interior. Cedar usually grows with several other conifers. It is most dominant on wet, cool sites on ultramafic soils, but reaches its largest size and commercial value on productive soils along the coast near the northern end of its range. Except on the most mesic, productive soils and some ultramafic areas, understory vegetation is shrubby and dense.

Port-Orford-cedar grows naturally where soil water is abundant throughout the summer. This limits the cedar to certain microsites, topographic positions, or soil types where water is abundant and, sometimes, competition is reduced; its topographic distribution is less limited in climates with higher summer humidity. It can also grow on hot sites with dry air and apparently can control summer water loss at low humidities. The cedar can grow on wetter sites than most associated conifers, but nonstagnant water may be required.

There is no simple explanation for the northern boundary of the range. Cedar appears to be more sensitive to water availability than are the common conifers in the region, but less sensitive to soil nutrient status or temperature.

Dramatic variability in tree form and growth rate occurs among individuals within the species, leading to over 200 cultivated varieties. Some regional variability in growth rate occurs within the species; the variability has not been described well, but seems likely to be of importance in choice of provenance in reforestation. Cultivars also vary in resistance to cold, mineral nutrition, and ability to root, but apparently not in resistance to root rot. Crossing with other Chamaecyparis species produces seeds that germinate poorly or seedlings without chlorophyll.

Cuttings of Port-Orford-cedar can be rooted easily, but most natural reproduction is sexual. Reproductive organs are initiated in spring and develop through the summer. Pollination occurs the following spring, and seeds mature by the October after pollination. Both sexes are borne on the same branches. First reproduction occurs at 5-9 years, but with the correct combination of gibberellins and photoperiod, plants only a few months old may be induced to produce viable seed. High seed production can occur in both old and young trees on both poor and excellent sites.

Seed crops seldom fail completely, and good crops occur at 4- to 5-year intervals; crops do not show the regional synchronization that some conifers do. Seed production averages 829 000/ha or 40 000/m^2 of cedar basal area. Seeds are small (2 mg each), but have a short dispersal distance. Most are shed by midwinter, but some seeds fall throughout the year. Germination percent is poor to moderate, but seed can be stored (frozen and sealed) for several years. Stratification is usually not required. Natural germination in the forest appears to be late--in early June. Seedling establishment is increased by soil disturbance and is usually adequate in clearcuttings close (50 to 80 m) to a seed source. Seedlings are easy to grow; a variety of ages of seedlings have been planted successfully, and cold storage of seedlings is possible.

Natural seedlings are small and grow slowly in shade. Growth after the sapling stage is less than for Douglas-fir, except on ultramafic substrates. Most conifers associated with Port-Orford-cedar in its native range are taller than the cedar when they are grown together in European plantations. Tree size varies twofold among natural forest communities. Large, old-growth trees average from about 30 to over 60 m tall and 43 to 86 cm in diameter. Trees 1 m in diameter are usually over 300 years old.

Port-Orford-cedar branches elongate more slowly and for a longer period during each growing season than do those of Pinaceae with which it grows.

Root systems may intermingle and graft freely but tend to be shallow. Roots are mostly of small diameter. Port-Orford-cedar forms vesicular-arbuscular mycorrhizae with several common, wide-ranging fungi.

The nutrient concentrations in Port-Orford-cedar tissue are variable, but the species is generally lower in nitrogen (N), phosphorous (P), and potassium (K) than are associated conifers. In contrast, cedar has higher concentrations of calcium (Ca) and sometimes magnesium (Mg), and a higher Ca:Mg ratio. Growth in culture on four soil types is highly correlated with foliar concentrations of K, and effects of N and P are important. Iron deficiency affects some cultivars.

Litter and soil under Port-Orford-cedar plantations are less acidic than those under associated Pinaceae. Development of amorphous humus is much less obvious than under Pinaceae.

Throughout its range, Port-Orford-cedar is shade tolerant and reproduces in old-growth stands, and it can act as both a pioneer and a climax species in the same stand. It reproduces in the shade more effectively than associated conifers do, except for western hemlock and sometimes white fir. Dense, young stands and some microsites in well-developed old growth are, however, too dark for its survival. The species usually establishes well, sometimes aggressively, in clearcuttings and other disturbed areas when seed is available. Its presence in mixed stands is thought to have little effect on productivity of more dominant species.

The extent of frost damage varies considerably as compared to associated conifers. Winter damage to Port-Orford-cedar usually results from desiccation rather than from low temperature alone. Port-Orford-cedar appears not to be especially susceptible to damage by wind or snow and can grow with moderate air pollution. Large trees have thick bark and survive fire. Many old-growth stands have burned repeatedly, and large fire scars are common. Small trees do not appear to have particularly great fire tolerance. Cedar rapidly reinvades burns and fire-killed snags may remain merchantable for special uses for decades.

Port-Orford-cedar has few biotic enemies that cause widespread serious damage, although effects of browsing are variable. The exception is a root rot caused by *Phytophthora* ***lateralis*** that has spread throughout much of the cedar's range since 1952. Stands have been eliminated from. some habitats, and the commercial status of the species is threatened throughout its range.

The root rot attacks only Port-Orford-cedar, and it kills trees of all sizes in all environments where the species is exposed to it. The root rot spread from an unknown source into ornamental plantings outside the native range, from there throughout the northern part of the commercial range, and now has reached all but the more remote areas of the range of the cedar. There is no known genetic resistance or established chemical control. The root rot moves in water via aquatic spores; as spores in mud transported by people, machinery, or animals; or by growing through root grafts between adjacent trees. Dry conditions reduce the danger of spread by spores but do not kill the fungus or its resting spores. The few data available indicate that soil at an infected site will contain infectious spores for 3 years after the last host tree has died.

Wood from Port-Orford-cedar has been used for many purposes, but its use has been limited by its supply, first to the Pacific Coast; then to certain specialty products; and, since the 1950's, to the export market, particularly Japan. High prices have been paid for it almost throughout its history. Production peaked in the 1920's and has generally declined since, although prices have continued to rise. Harvest has been accelerated by the effects of root rot and presently exceeds growth.

Heartwood of Port-Orford-cedar is relatively strong and light, very resistant to decay, and easy to machine; it can fill a large variety of uses. Wood produced by second growth is as suitable for structural use as is old growth. In contrast, wood grown in Great Britain is less desirable, relative to other species, than that from the United States. Since the 1960's, the high price for old-growth timber has depended more on the aesthetic value of wood exported to Japan than on the intrinsic physical or chemical properties of the wood. Oil in Port-Orford-cedar wood is toxic to termites and other decay organisms, and may also cause discomfort in workers continually exposed to it.

Mean annual volume increments of 60-year-old stands in Oregon are about 14 to 17 m^3/ha. Stands in Great Britain are grown more densely than other conifers, and mean annual increment peaks at age 55-70, 5-15 years later than for Douglas-fir. Some stands of old growth have yielded over 1400 m^3/ha; some small areas still bear 280 m^3/ha. Large areas average much less--40 to 150 m^3/ha over several hundred hectares.

Although management in the presence of the root rot is difficult, we believe that future rotations can be produced, and that management of cedar can be beneficial for economic as well as for aesthetic and biological reasons. Management requires long-term commitment by the landowner, however, and must emphasize allowing cedars to escape the disease. Spread of inoculum must be limited and can be accomplished by keeping equipment clean, working in dry weather, and eliminating pockets of infection. Cedar must be limited to specific locations that are unlikely to become infected. Limiting access, locating roads, and conducting all management activities so that spores do not reach stands are important.

Not much planting of Port-Orford-cedar has been done, but the little that has, has been successful. Precommercial thinning may unintentionally eliminate cedar as a crop tree if done by size alone. Some control of cedar density and tree location can both preserve cedar in the stand and reduce the chance of tree-to-tree spread of root rot.

Contents

Chapter 1: Introduction

Port-Orford-cedar ***(Chamaecyparis lawsoniana*** [A. Murr.] Parl.) is a valuable forest tree within its limited geographic range. Its value has increased faster than that of the major lumber species in both the domestic an foreign markets (Ruderman 1979) and reached astumpage price in one sale of $5,440 per thousand board feet (USDA, Forest Service 1979). Demand for its wood, almost all of which is exported to Japan, continues to be high and has not been closely synchronized with fluctuations in the domestic market. Significant problems beset the continued production of the species, however. Slow growth (relative to Douglas-fir ***[Pseudotsuga menziesii*** (Mirb.) Franco]) and losses to frost and animals in plantations outside its natural range diminished silvicultural interest in Port-Orford-cedar (Hunt and Dimock 1957, James 1958). During a period of low demand, and following the introduction of a devastating root rot, interest essentially disappeared. The root rot continues to spread, and no usable natural resistance has been found. The dilemma of managing a valuable but slow-growing, less common conifer in mixed stands, in an age of high interest rates and shortened rotation periods (as Minore [1983] discussed for western redcedar), is exaggerated for Port-Orford-cedar. Even so, as the price of Port-Orford-cedar has risen, interest in managing the species has increased and foresters are reassessing the possibility of sustainable production in spite of root rot.

Although the biology of the fungus, ***Phytophthora lateralis,*** that causes the fatal root rot of Port-Orford-cedar is incompletely known, useful information has accumulated. Once a tree is attacked there is no known cure, but the fungus seems to disappear rapidly from the soil once the cedar dies. The major natural agent that disperses the fungus is running water. Mud moved by machinery from an infected to an uninfected stand provides the principal effective inoculum. The movement of the pathogen can be predicted and, to a lesser degree, controlled. Management without both resistance of the tree to infection and an effective control method may be possible, given sufficient collaboration among pathologists and forest managers.

Port-Orford-cedar became commercially important as an ornamental in Europe soon after its discovery by horticulturists in 1854. Over 200 cultivars have been produced that vary in size, form, color, and foliar patterns; some have been used for over a century. The cultivars are most popular in Europe, but are used in many temperate areas. The cedar root rot, originally described from an ornamental nursery in Washington, destroyed a thriving nursery industry in the Pacific Northwest that had been based on cedar.

Port-Orford-cedar presents some problems of considerable interest to ecologists: What attributes allow it to grow on many ecologically different sites, but at the same time severely limit its geographic distribution? Why is growth of Port-Orford-cedar less affected on sites and at ages that drastically curtail growth of the regionally dominant conifers? Port-Orford-cedar possesses the unusual combination of tolerance to shade, and, by midlife, to fire. A member of the family Cupressaceae, its ecology may differ significantly from the conifers of the Pinaceae, which are the most often studied.

Our purposes are to review the biology of Port-Orford-cedar and its most important pathogen, to review the history of its management, and to propose guidelines for its future management in the presence of the root rot. Information from past and current unpublished research and management practice is used, as well as the rather limited literature on the species. Much of the literature, unfortunately, is based on work outside the native range.

Chapter 2: Geographic and Habitat Distribution

Port-Orford-cedar is native only to southwestern Oregon and northwestern California (Little 1971) in the Klamath Mountains, the southern end of the Coast Range in Oregon, and the northern end of the Coast Ranges in California, and on coastal and alluvial terraces and coastal dunes. Its distribution is highly localized within most of its range (figs. 1 and 2), and the extent of stands is hard to estimate accurately.

The USDA Forest Service range map (Little 1971) incorrectly shows that the cedar is present on the immediate coast of southern Oregon, although its absence is clearly indicated on an earlier map (Port Orford Cedar Products Company 1929). The northern disjunct location in Lane County, OR (shown by Little 1971), has been difficult to relocate, except for planted trees. A forest survey plot indicating Port-Orford-cedar in Lane County, OR, appears to contain western redcedar *(Thuja plicata* Donn ex D. Don) instead.

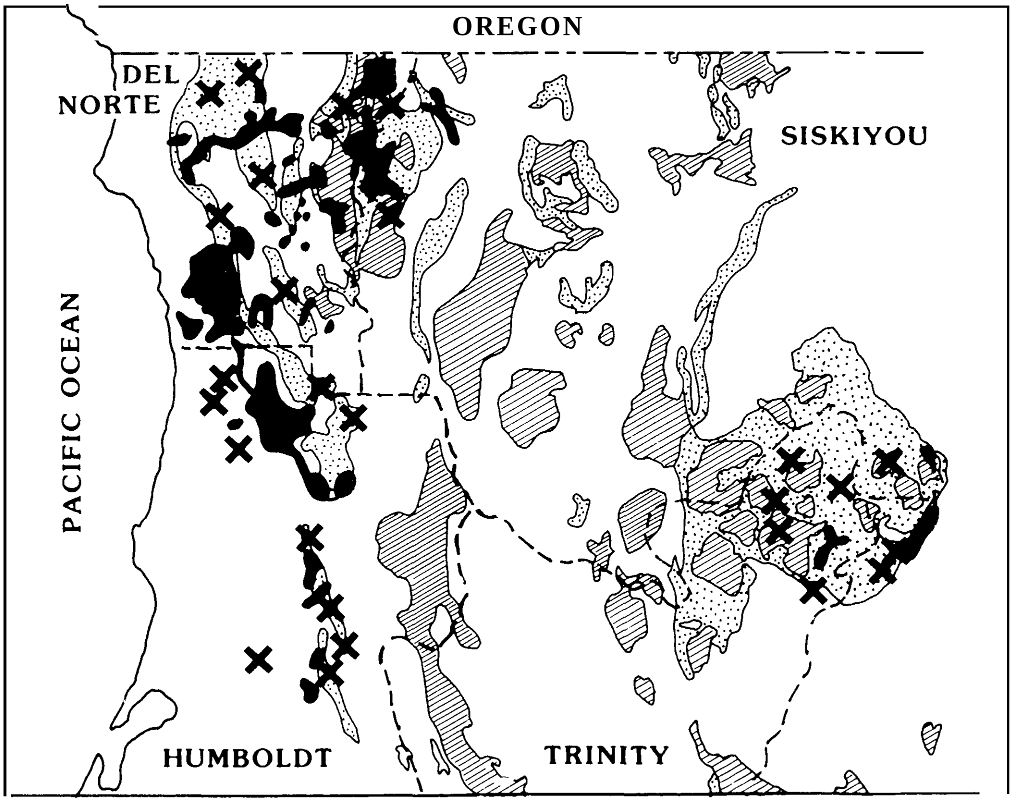

Figure 1.—Distribution of Port-Orford-cedar in California in relation to geology. Redrawn from Griffin and Critchfield (1972) and Page (1966). Black areas and X's are locations of cedar; stippling indicates ultramafic rocks; hatching indicates granitic rocks; dashed lines are county boundaries.

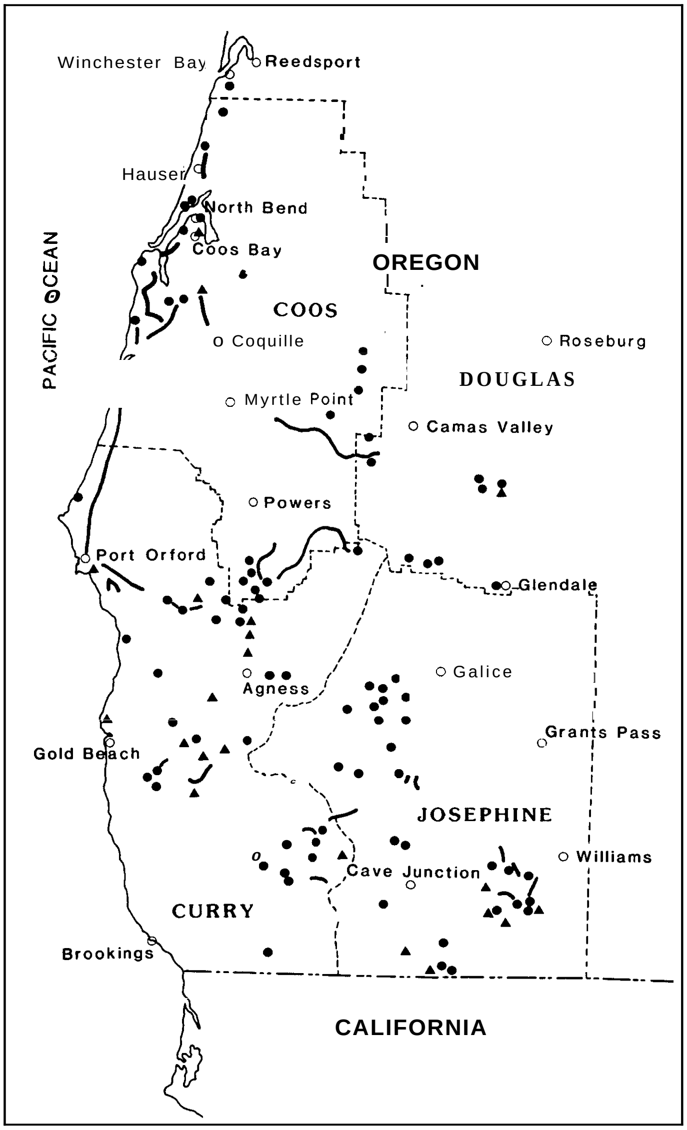

Figure 2.—Distribution of Port-Orford-cedar in Oregon. Locations indicated by (A) are those of herbarium specimens; those indicated by (O) are observations by recent observers looking specifically for the species or are from a 1925 USDA Forest Service map. Dark lines are roads along which the species has been observed at least once every mile. Cities are shown as (o).

The greatest concentration of Port-Orford-cedar is in Oregon in the northern third of its range, on the coastal hills and terraces from Coos Bay to Port Orford and in the adjacent southern edge of the Coast Range in Oregon, including the drainages of the middle and south forks of the Coquille River. Secondary concentrations occur inland at moderate to high elevations near the Oregon-California border, and in the watersheds of Grayback Creek and Deer Creek in southeastern Josephine County, OR (Atzet 1979, Hawk 1977), and of upper Clear Creek in northwestern Siskiyou County, CA (Siemens 1972). Throughout most of its range, however, Port-Orford-cedar grows in small, disjunct stands. A group of stands widely separated from the bulk of the range occurs inland in California along the upper reaches of the Trinity and Sacramento River systems near the juncture of Siskiyou, Shasta, and Trinity Counties. Early sources (Port Orford Cedar Products Company 1929, Sudworth 1908) indicate its presence farther south than is shown on recent range maps.

Port-Orford-cedar grows from sea level (Hawk 1977) to subalpine forests (Siemens 1972). It reaches 1950 m in the upper Sacramento River drainage[1] Cedar occupies dune sand; organic bog soils; soils developed on diorite, gabbro, serpentine, peridotite, several other rock types, and river alluvium; the Blacklock soil series on coastal terraces (which supports only pigmy conifers in Mendocino County, CA) (Jenny and others 1969, Westman 1975); and in the area of its greatest commercial value, soils developed on sedimentary rocks. Climate varies; the cedar's range includes the coastal fog belt, relatively dry interior valleys, and extends into the subalpine. Port-Orford-cedar occurs in all four vegetation zones recognized in southwestern Oregon (Franklin and Dyrness 1973) and in the montane, subalpine, mixed evergreen, and north coastal forest regions of northwestern California (Barbour and Major 1977). The tree also occurs in local azonal vegetation types on coastal dunes, inland river terraces, and bogs on ultramafic outcrops (Hawk 1977). Port-Orford-cedar grows on a variety of land forms.

The diversity of habitat implied by the preceding description does not occur on a local basis, however. Within a given locality, the tree is often restricted to a single edaphic situation; that is, to sites with year-round seepage throughout much of its range, and in addition, inland at low elevations south of Coos County, OR, to soils from ultramafic parent materials (peridotite, serpentinite). At its northern limit, it grows on Recent and Pleistocene coastal sand dunes. Where it is most prevalent, Port-Orford-cedar occupies a wider variety of land forms and substrates. The general relationships of elevation, parent material, geographic location, and forest type where Port-Orford-cedar is usually found are shown in figure 3.

Chapter 3: Environment

Climate

The climate where Port-Orford-cedar grows has warm, dry summers and cool, wet winters, but varies considerably with proximity to the ocean and with elevation (fig. 4, table 1). Long-term climatic data are available for a few coastal and valley-bottom weather stations (table 2). There is a 10 percent chance of frost (0 °C) during 165 days per year at North Bend (on the coast), 243 days at Powers (in the Oregon Coast Range), and 307 days in Josephine County (in the Klamath Mountains) (Eichorn and others 1961, Sternes 1968). The climate is described by Atzet (1979), Buzzard and Bowlsby (1970), Cooper (1958), Hawk (1977), Major (1977), Meyer and Amaranthus (1979), Sternes (1968), and Whittaker (1960).

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[1] Personal communication, 1980, R. Kelly, Berkeley, California.

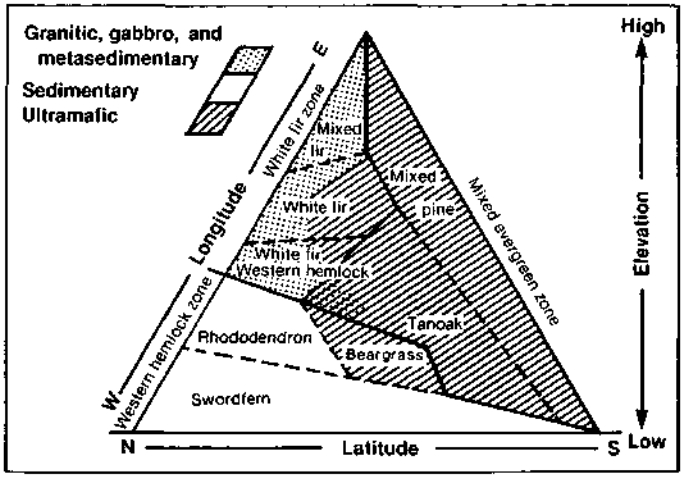

Figure 3.—Distribution of vegetation zones and eight major forest communities of old-growth Port-Orford-cedar in relation to soil parent material, elevation, and geographic location. Zones (described in Chapter 4) are separated by heavy solid lines and communities by dashed lines (modified from Hawk 1977).

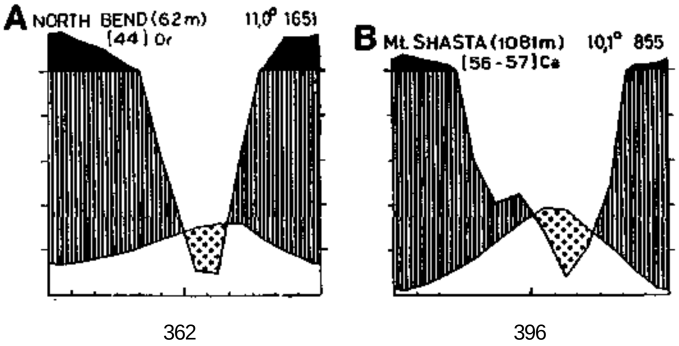

Figure 4.—Climate diagrams (Walter and others 1975, used courtesy of Springer-Verlag New York, Inc.) representing (A) the northern coastal range and (B) the area just outside the interior southern parts of the range of Port-Orford-cedar. The x-axis represents months of the year. The lower curve on the graph represents temperature, the upper curve precipitation. The stippled portion represents the relative period of drought. Figures in the top line are elevation, mean annual temperature (°C), mean annual precipitation (millimeters), and (years of record).

Table 1—July and January mean temperature data for the range of Port-Orford-cedar in Oregon and California

(In degrees Celsius)

Item	Oregon	California
July:		
Mean minimum	7 to 12	8 to 12
Mean maximum	20 to 32	18 to 33
January:		
Mean minimum	-2 to 5	-3 to 5
Mean maximum	6 to 12	6 to 12

Source: Hawk 1977.

Table 2—Climatic variation within the range of *Chamaecyparis lawsoniana,* 1951-60

Region and station	Latitude (N)	Distance inland	Elevation	Precipitation			Mean temperatures		
				Annual	Jun-Aug	Snow	Annual	Coldest month minimum	Warmest month maximum
		km	m	- - - - - - mm - - - - -			- - - - - - °C - - - - - - -		
Coast:									
North Bend FAA-AP	43°25'	5	3	1579	64	3	11.2	4.2	19.0
Klamath	41°31'	3	8	2185	62	ND	11.6	4.1	19.8
Coast Ranges and Siskiyous:									
Sitkum 2 SW	43°08'	43	173	2159	73	201	11.6	1.7	25.5
Powers	42°53'	34	92	1655	56	ND	11.9	2.5	24.3
Illahe	42°39'	28	113	2253	48	363	13.1	2.3	31.4
Oregon Caves National Monument 1/	42°06'	68	1220	1753	64	4445	7.8	-2.3	25.9
Elk Valley	42°00'	41	357	2187	44	ND	10.4	-.3	30.1
Interior California:									
Mount Shasta WB City 2/	41"19'	149	1081	1019	37	3550	9.8	-3.3	29.7
Dunsmuir	41°13'	152	738	1590	52	ND	ND	ND	ND

ND = no data given.

1/ Data for 7 years from Atzet (1979).

2/ Station outside, but within 5 km, of range of C. lawsoniana.

Source: U.S. Weather Bureau unless otherwise noted.

Table 3—Snow depths at snow survey sites in the range of Port-Orford-cedar

Location	Elevation	Measurement date	Years of data	Mean depth	Range of depth
	Meters			- Centimeters -	
Page Mountain, Josephine Co., OR	1235	Jan–Apr 1/	18	53	3–183
Mumbo Basin, Trinity Co., CA	1739	April	13	161	64–274
Gray Rock Lakes, Siskiyou Co., CA	1891	April	17	264	165–526

1/ The data used are, for each year, the maximum of 3 measurements, 1 each taken in late January, late February, and late March to early April.

Source: George and Haglund 1973, Hannaford 1959.

Total precipitation is moderately high. The eastern boundary of the range in southern Oregon coincides approximately with the 1000-mm limit (USDA Soil Conservation Service 1964). In California, most stands receive at least 1500 mm (Rantz 1968), and inland disjunct populations receive at least 1250 mm precipitation. South and east of its range, in general, rainfall decreases and evaporative stress increases (Johnsgard 1963, Thornthwaite Associates 1964, Walter and others 1975). Along the coast south of the range, however, are areas with the same precipitation and evaporation as within the range of Port-Orford-cedar so, unlike the drying along the eastern boundary, there appear to be no abrupt climatic changes across either the southern or the northern ends of the range.

A major climatic break within the range exists between the Coquille River drainage, with its extensive commercial stands of Port-Orford-cedar, and the adjacent Rogue River Valley to the south. The Coquille valleys, open to the northwest, often have low clouds borne on strong northwest winds in the summer; the clouds often dissipate as they cross into the Rogue River Valley, which is open to the dry interior valleys to the east. Fog along the lower Rogue River is common but usually restricted to the valley bottom. Temperature differences between Powers and Illahe demonstrate the more maritime climate in the Coquille drainage at Powers (table 2).

Snowfall varies from rare along the coast to an accumulated snow pack of 1 m or more at high elevations (tables 2 and 3) (Sternes 1968).

Relative humidity along the coast in Oregon is high, with a monthly average at 4:00 p.m. of 71 to 74 percent during the growing season and 82 percent in January. The average monthly reading for 4:00 a.m. is never below 89 percent. Two-thirds of the days (ranging from 30 percent of days in July to 80 percent of days in January) are cloudy in this area (Buzzard and Bowlsby 1970). The daily minimum humidity at Oregon Caves National Monument at 1200 m elevation in southeastern Josephine County, OR, averages 39 percent and the maximum is

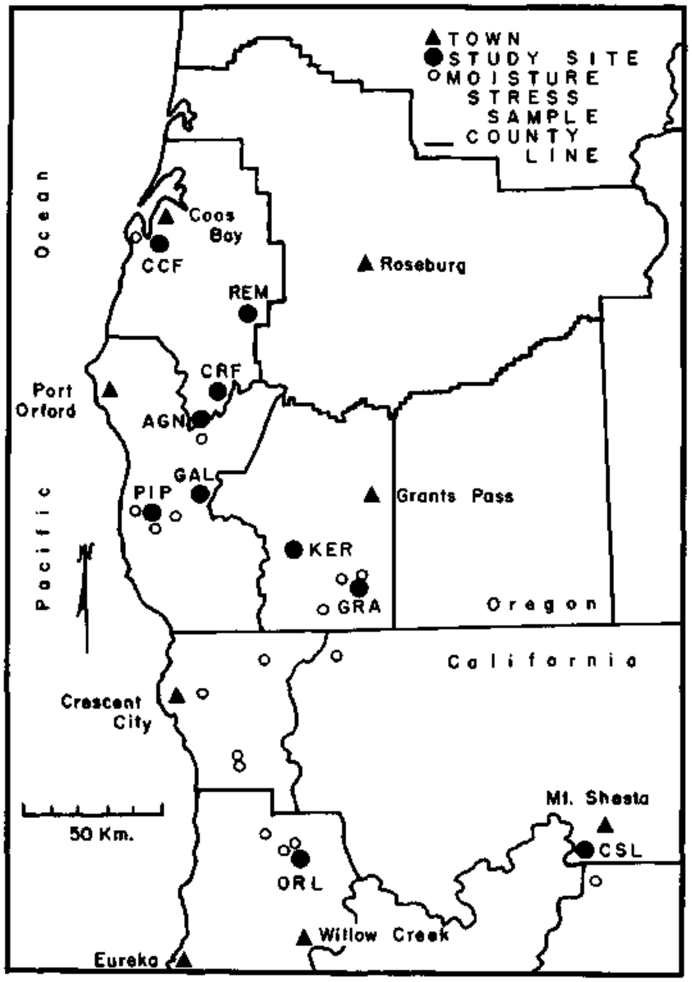

Figure 5.—Ten primary study sites where temperature, foliar nutrient content, understory light intensity, water potential, and seed production were sampled, and of secondary sites used for sampling water potential. Sites, north to south, are: CCF, Coos County Forest; REM, Remote; CRF, Coquillle River Falls; AGN, Agness Pass; GAL, Game Lake; PIP, Pine Point; KER, Kerby; GRA, Grayback; ORL, Orleans; CSL, Castle Lake (from Zobel and Hawk 1980 used courtesy of *American Midland Naturalist).*

84 percent during the driest month (Atzet 1979). In contrast, humidity in open, low-elevation stands can be very low. Vapor pressure deficit reached 47.5 millibars at Kerby (fig. 5) and averaged 23.5 millibars for the driest day in the one summer measured; the maximum reached at Coos County Forest on the coast that summer was 10 millibars (Zobel and Hawk 1980). Fog is common along the coastline and morning fog also occurs along the lower part of major drainages in the Oregon Caves area (Atzet 1979).

Average wind speed at Coos Bay is lowest in autumn and highest in July (Buzzard and Bowlsby 1970). Summer winds (May to September) are almost all from north to northwest. From November to March, winds from the south to southwest are

Table 4—Temperatures in the air, 1 m above the soil, and in the soil, 20 cm below the forest floor, under 10 stands of Port-Orford-cedar, September 1974 to September 1976

Vegetation zone and community	Site	Air temperature			Frostless season in 1975	Soil temperature		
		Mean annual	Minimum in coldest month 1/	Maximum in warmest month 1/		Annual	Coldest month	Warmest month
		- - - - - - - °C	- - - - - - - -	- - - - - - - -	days	- - - - - - °C	- - - - - - -	- - - - - - -
Tsuga heterophylla:								
Sandstone	Coos County Forest	8.9	+2.2	17.7	225	9.8	6.8	13.2
Swordfern	Remote	8.2	+ .8	19.0	197	8.3	4.1	13.2
	Coquille River Falls	8.4	+ .8	22.7	185	7.9	4.0	12.2
Mixed evergreen:								
Tanoak	Agness	6.9	-2.1	25.2	155	7.6	3.6	13.5
	Pine Point	8.8	- .3	23.5	124	9.2	5.4	13.7
	Orleans	7.5	-1.0	22.2	NA	6.9	5.1	9.1
Mixed pine	Kerby	10.9	- .4	34.9	233	11.3	8.3	15.0
Abies concolor:								
White fir	Game Lake	NA	-1.6	20.1	NA	NA	NA	12.3
	Castle Lake	4.4	-6.7	23.6	52	3.9	.4	9.0
Mixed fir	Grayback	5.7	-2.7	18.4	NA	4.8	1.4	9.3

NA = insufficient data available.

1/ "Warmest month" and "coldest month" data are means of the mean maxima and minima of air, and the mean monthly temperature of soil for the appropriate months in both years of the study.

Source: Zobel and Hawk 1980.

strongest and most common.[2] Storm winds can be severe. On November 13, 1981, for example, wind speed reached 198 km per hour at 61 m elevation at a typical site in coastal Coos County, and remained above 80 km per hour for 7 hours (see footnote 2).

Table 4 and figure 6 summarize means of temperatures for 2 years as measured 1 m above the forest floor in 10 natural cedar forests throughout the range (Zobel and Hawk 1980). The extreme low air temperature recorded within the range was -15 °C (compared with a low of -19 °C for the Mount Shasta U.S. Weather Bureau station). Temperature fluctuations within the range appear to be synchronized by the movement of air masses inland from over the ocean. Areas near the coast show the most variation from the general pattern as summer fog usually coincides with hot weather inland. In the region where Port-Orford-cedar grows, summer temperatures remain higher later in the year than they do in surrounding areas. This pattern, which results in warmer September averages, is obvious in the northern part of the range and even more so for temperatures in stands than for those at the nearest weather stations (Zobel and Hawk 1980).

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[2] Personal communication, 1984, J. Wade, Oregon State University, Corvallis.

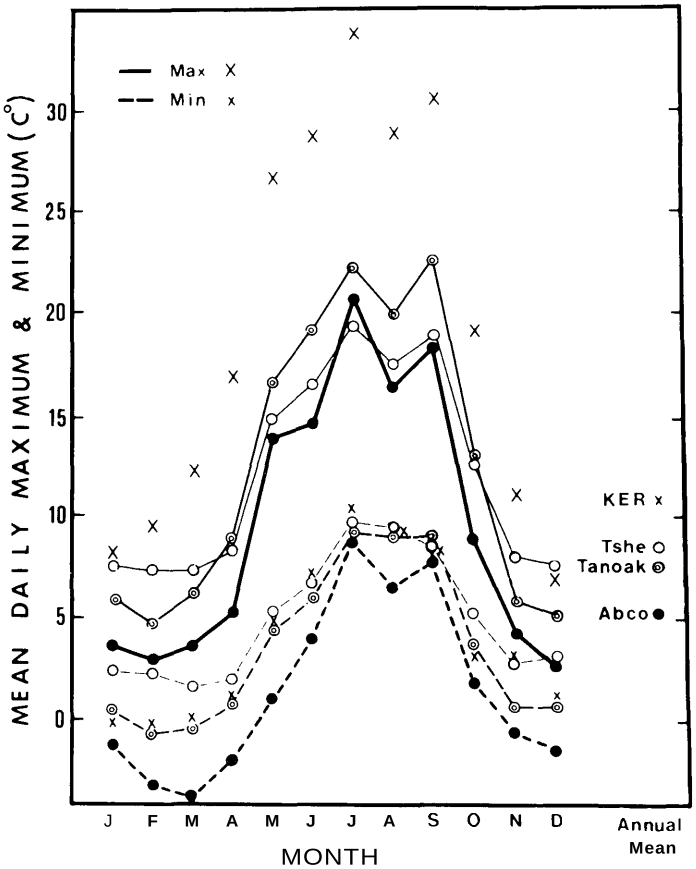

Figure 6.—Mean daily maximum and minimum temperature in the forest understory, and annual mean temperature by zone. Mixed Evergreen zone data are presented separately for the tanoak community and for the mixed pine community at Kerby **(X).** "Abco" represents the Abies concolor zone; "Tshe" is the ***Tsuga heterophylla*** zone. Sites sampled are listed in table **4** and their locations are shown in figure 5 (from Zobel and Hawk 1980, used courtesy of American Midland Naturalist).

Port-Ordord-cedar stands are generally cold and temperature varies relatively little during the year (fig. 7, table 5), especially on sites with active year-round seepage. Soils do not appear to freeze often, even at high-elevation sites. Port-Ordord-cedar grows on many of the available substrates (table 6) and landforms (table 7).

Some definite relationships occur among substrate, topography, and other environmental factors in the habitat of Port-Orford-cedar (see fig. 3) (Hawk 1977, Whittaker 1960, Zinke 1977).

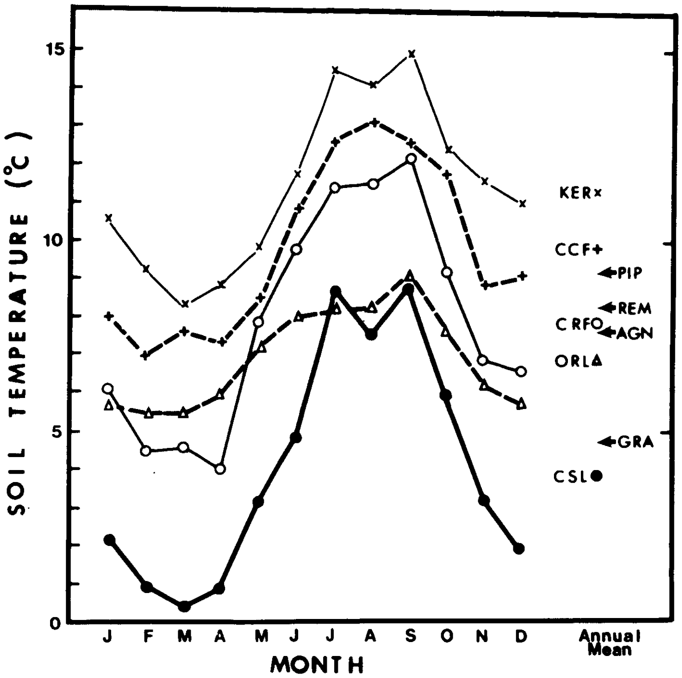

Figure 7.—Mean monthly soil temperature (20 cm deep) for five sites, with mean annual soil temperature for nine sites. See table 4 and figure 5 for site characteristics and locations (from Zobel and Hawk 1980, used courtesy of ***American Midland Naturalist).***

Table 5—Mean maximum and minimum temperatures of litter and soil at four sites, valley of the South Fork Coquille River[1]

(In degrees Celsius)

	Litter		-10 cm soil	
Period	Minimum	Maximum	Minimum	Maximum
16 Jun-15 Jul	8.9	12.2	9.7	10.3
16 Jul-15 Aug	11.2	15.5	12.3	13.0
4 Sep-26 Sep	11.4	14.7	12.1	12.7
3 Jan-5 Jan	6.1	6.9	5.9	6.1
Extreme values	- .2	16.9	2.2	14.5

[1] Data are means for the period indicated in the understory in four forests for 1979 to 1980, except "extreme values," which are the highest or lowest recorded at any site during the entire period.

Source: Imper 1981.

Table 6—Predominant rock types that underlie 105 stands throughout the range of Port-Orford-cedar

Rock type	Number of stands
Ultramafic (peridotite, serpentinite)	51
Diorite, gabbro, other intrusive	22
Sedimentary	21
Recent alluvium	4
Schist	3
Metavolcanic	2
Others	2

Source: Hawk 1977.

Table 7—Landform and position of 98 stands throughout the range of Port-Orford-cedar

	Position		
Landform	Top slope	Midslope	Bottom slope [1]
Ridgetop	--	1	--
Sideslope	7	27	--
Bench	12	20	--
Drainageway	5	25	1

-- = none.

[1] Absence of sampling plots on the bottom slope position reflects in part the almost universal disturbance of Port-Orford-cedar forests in these areas.

Source: Hawk 1977.

Geology and Topography

Port-Orford-cedar grows in a region that has extremely complex geological patterns (Baldwin 1974; Baldwin and others 1973; Beaulieu and Hughes 1975; Davis 1966; Dott 1971; Harper 1983; Hotz 1971; Irwin 1981; Page 1966; Ramp 1975; Ramp and Peterson 1979; Ramp and others 1977; Robertson 1982; Strand 1969, 1973; and Whittaker 1960). The major commercial forests and the northern extremity of the range in Coos County are underlain primarily by Eocene sedimentary rocks. A primary source area for these sediments was the complex, older Klamath Mountains province to the south, which includes most of the range of Port-Orford-cedar. North, beyond the range of the cedar, the source and physical nature of the sediments changes, but no significant differences in the chemical composition of rocks inside and outside the range have been noted (Dott 1966).

Near the northern limit of Port-Orford-cedar in Coos County, the species is most common on Quaternary sediments on marine terraces, sand dunes, deflation plains, and the underlying Eocene Coaledo formation sedimentary rocks within 6-7 km of the ocean. At the apparent northeastern limit in Douglas County (see fig. 2), old trees occur primarily on north-facing cliffs on siltstone of the Eocene Tyee formation, although the cedar has become more widespread following clearcutting. South of Coos Bay, the best-developed, early-exploited forests of Port-Orford-cedar (Sargent 1881) grew on high terraces along the coast and on several Eocene sedimentary formations on slopes below the terraces. Inland, in the higher elevations of the southern Coquille River drainage, the trees grow on Eocene sediments (apparently primarily Lookinglass and Tyee formations) and Quaternary alluvium, as well as on the Jurassic Galice formation and accompanying ultramafics, which comprise the northern end of the Klamath Mountain Rocks.

In the Klamath Mountains, the oldest Paleozoic rocks are in the eastern portion just north of Redding, CA. Four convex bands of successively younger rocks (to Jurassic) occur to the west, extending north to Douglas and southern Coos Counties, OR. These sediments and volcanics have mostly been metamorphosed and are accompanied by large bodies of ultramafic rocks, which lie in arcs along major fault zones separating the bands of differently aged rocks. Most of the ultramafic rock is peridotite; much of it has been converted to serpentinite. Granitic rocks intruded at a later time. The region was subjected to intense faulting and deformation and repeated uplift until the early Eocene.

Some populations of Port-Orford-cedar along the lower Klamath River and its tributaries grow on the Franciscan formation, which lies,west of Klamath Mountain rocks at the north end of the California Coast Ranges.

The Klamath Mountains are rugged and deeply dissected; much of the terrain is unstable, especially that underlain by ultramafic rocks and schists. The highest areas of the Klamath Mountains in California were modified by local alpine glaciation, and Port-Orford-cedar occupies moraines near its upper elevational limit in Cedar Basin, in the upper Sacramento River drainage? The topography is lower and more subdued on younger rocks along the coast and in the north, but the mountains are still steep. Along the coastline, especially in the north, flat, wave-cut terraces occur up to 500 m above present sea level.

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[3] Personal communication, 1983, J.O. Sawyer, Humboldt State University, Arcata, California.

Table 8—Rock types that underlie vegetation units with >5 percent cover of Port-Orford-cedar in mountains along the lower Klamath River and west of the lower Trinity River, Humboldt and Del Norte Counties, CA

Iinportance	Number of stands	Serpentine	Ultrabasic igneous	Metamorphosed basic igneous	Schistose sedimentary	Sandstone and shale	Soft sedimentary rocks
		Percent					
>5 percent	197	2	15	13	51	17	2
Important 1/	72	--	14	22	44	17	3

-- = none.

1/ "Important" means the species was the first or second most abundant species.

Source: USDA Forest Service and others 1960-1962.

In the valley of the South Fork Coquille River, Port-Orford-cedar is important on a wider local variety of rock types and topography than anywhere else (Hawk 1977). The best development of the cedar seems to occur in topography created by land slumping, such as at Coquille Falls Research Natural Area. In the Klamath Mountains geologic province in and south of the Rogue River Valley (especially at low elevations), Port-Orford-cedar is limited primarily to benches and drainageways in or below ultramafic rocks (Hawk 1977, Zinke 1977). Major exceptions are in the highlands of southeastern Josephine County, OR, and near the mouth of the Klamath River in California. In southeastern Josephine County, Port-Orford-cedar is common on a large intrusion of diorite (Whittaker 1960), and importance of cedar increases above 800 m. In the upper South Fork Deer Creek drainage, cedar occurs on metavolcanic rocks of the Applegate group. In the coastal mountains along the lower Klamath River and west of the lower Trinity River (areas not sampled by Hawk [1977]), Port-Orford-cedar grows on a variety of rock types with the majority of mapping units located on sedimentary rocks (table 8). West of Orleans, CA, it grows on the Galice formation (Sawyer 1980, Sawyer and others 1977).

Stands from the Coast Range in Oregon and high elevations in the northern Klamath Mountains often occupy top-slope positions and side-slope landforms. In contrast, low-elevation and southern Klamath Mountain forests are most common on benches and in drainageways. Soils in 81 percent of the plots in Hawk's (1977) major communities developed from colluvial materials; 47 percent of the parent materials were entirely colluvial, especially in sedimentary and less basic intrusive rocks. In contrast, only 28 percent included some alluvium and 32 percent were partially from residual parent materials (mostly on ultramafic rocks).

In most areas, a critical factor for the presence of Port-Orford-cedar seems to be a consistent supply of seepage water. Substratum and topography contribute to occurrence of seepage but do not themselves seem to be sufficient for presence of the tree. South of the Coquille River drainage, all stands sampled (fig. 5) had a water table within 70 cm of the surface (Zobel and Hawk 1980). Seepage was often obvious and rapid. On ultramafic substrates, the water table was perched above a dense layer of fine clay.

Soils

Field characteristics.—Summary descriptions of soil profiles presented here (tables 9 and 10 and in text) for eight major forest communities (see Chapter 4) where Port-Orford-cedar occurs are from Hawk's (1977) vegetation plots located thoughout the range.

Swordfern community.—Most stands occur on benches of shallow relief, and all occur on sedimentary parent materials.

Rhododendron community—All stands occur on sedimentary parent materials. These soils include coarser fragments, are better drained, are on generally steeper topography, and are on upper slopes or side slopes rather than on benches or terraces, in contrast to the swordfern community.

Beargrass community—Stands all occur on ultramafic parent material (mostly serpentinite, but also some dunite and peridotite). The two major areas are in the contact zone between ultramafic and granitic formations, with some metamorphosed sedimentary rocks also present. Average soil depth to the C horizon is only 47 cm; soils on ultramafic rocks are shallower (35 cm) than those including other parent materials (59 cm). These soils occur typically on side slopes or undulating topography similar to that of the rhododendron community.

Tanoak community—This community occurs on ultramafic substrates similar to those of the beargrass community but where moisture conditions are similar to those of the rhododendron community. It is commonly found on perennial stream drainage benches and on gently rolling topography with common seeps or standing water.

Mixed pine community—All stands in this community occur on either weakly weathered serpentinite or, most commonly, peridotite. This community has been separated by Hawk (1977) and Whittaker (1960) into shrub- and herb-matrix phases, which occupy noticeably different microhabitats. The shrub phase occurs on benches and drainages with slopes averaging about 15 percent; the herb phase occurs on midslopes with an average slope of 34 percent. Depth to the surface of the C horizon averages 32 cm (42 cm in the shrub phase and 19 cm in the herb phase).

White fir-hemlock community.—Parent materials include quartz diorite, metavolcanics, mixed gneiss, schists, and gabbro, all of which are complexly intruded with peridotite and serpentinite. A mixture of metavolcanic, metasedimentary, and ultramafic rocks is common within most soils. Soils are comparatively shallow, typically developed on colluvium, or mixed alluvium and colluvium, and contain much coarse material.

White *fir/herb* community—The predominant parent material is at least partially ultramafic with some volcanic materials at a few locations.

Mixed *fir/herb* community—Parent materials are variable, with many being dioritic colluvium. Some stands occur on sedimentary or volcanic parent material. Soils are usually moist and well-drained, and contain many coarse fragments. Most are deep and moderately developed. This is the coarsest group of soils in any of the eight major plant communities.

Table 9—Soil depth, to the top of the C horizon, and soil texture, by horizon, for eight major plant communities of Hawk (1977)

	Depth (A+B horizons)		Texture by horizon 1/		
Community	Mean	Range	A	B	C
	---- Centimeters ----				
Swordfern	67	40-117	gSL	g,cOSCL	g,coSCL
Rhododendron	73	40-100	SL	g-COSL	g,coSCL
Beargrass	47	15-95	gSL	g,cOSCL	g,co,stCL
Tanoak	69	28-105	g,COSL	g,coSL-SCL	g,co,stSCL-CL
Mixed pine	32	5-50	g,stL-C	g,co,stSCL	g,co,stSC-C
White fir-hemlock	43	23-70	g,COSL	g,co,stSCL	vg,co,stSa-SCL
White fir	41	21-65	g,coSL	g,COSL-CL	vg,COSL-CL
Mixed fir	65	30-105	g,coSL-SaL	vg,coSaL	vg,coSaL-L

1/ S = silt or silty; Sa = sand or sandy; C = clay; L = loam; g = gravelly; co = cobbly; st = stony; v = very; - = to.

Source: Unpublished date on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Table 10—Structure, dry consistency, and wet consistency of surface soils and subsoils for eight major plant communities of Hawk (1977)

	Surface soils			Subsoils		
		Consistency			Consistency	
Community	Structure 1/	Dry 2/	Wet 3/	Structure 1/	Dry 2/	Wet 3/
Swordfern	SM-CG,Cr	Fr	sStP-nSnP	S,MSB or MX	F	StP
Rhododendron	WF-MCr, G	L-F	nSt,nP	MCG-SB or MX	Fr-H	sStP-StP
Beargrass	S-M,F-C,G	Fr	nStP-s StP	SG-SB or MX	F	sSt,np-StP
Tanoak	S,F-MG	Fr	sStP	S-M,F-CSB or MX	Fr-F	StP
Mixed pine	MF-MeGr	L-H	sStP	W-M,vF-CGr or SB	L-H	StP
White fir-hemlock	W-M,FCr-MeSB	Fr	vsSt,nP	SF-C,SB-MX	Fr-F	sStP
White fir	WvFCr	L-F	sSt,s-nP	WvF-CGr-SB or MX or LSG	Fr-F	sstP
Mixed fir	WF-CG, Cr	L-F	nStP-sStP	W-S,vF-CG-MeSB or MX	Fr-F	StP

1/ S = strong; M = moderate; W = weak; C = coarse; Me = medium; F = fine; LSG = loose single grain; G = granular; Cr = crumb; SB = subangular blocky; AB = angular blocky; MX = massive.

2/ L = loose; Fr = friable; F = firm; H = hard.

3/ St = sticky; P = plastic; nSt = nonsticky; nP = nonplastic; StP = sticky and plastic; s = slightly; v = very.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Table 11—Laboratory analysis of texture of four soils under Hawk's (1977) Swordfern Community in the valley of the South Fork Coquille River

Site	Horizon	Depth	Sand/silt/clay	Textural class 1/
		cm	percent	
Ash Swamp 2/	A1	0-8	45/20/35	CL
	A3	8-45	43/21/35	CL
	B	45-75	46/22/32	SaCL
	C	> 75	35/33/32	CL
Coquille River Falls Research Natural Area	A1	0-12	54/23/23	SaCL
	A3cn	12-26	50/24/26	SaCL
	B1cn	26-40	57/18/25	SaCL
	B3	40-95	47/25/28	SaCL
	C	> 95	60/23/17	SaL
Squaw Lake	A	0-10	66/18/16	SaL
	C	> 10	72/17/11	SaL
Port-Orford-Cedar Research Natural Area	A1	0-15	39/18/43	vgC
	B21t	15-45	34/15/51	vgC
	B22t	45-90	22/23/55	vgC
	C	> 90	20/25/55	vgC

1/ C = clay; L = loam; Sa = sandy; vg = very gravelly.

2/ Parent material of the first site was Quaternary alluvium; that of others was sedimentary rocks.

Source: Imper 1981.

Additional sites in Hawk's swordfern community in Coos County, OR, were analyzed in the laboratory for texture (table 11); they have a wider range of textures than Hawk's data indicate. Other brief soil descriptions of areas with Port-Orford-cedar are given for three Research Natural Areas in Oregon (Franklin and others 1972).

Table 12—Occurrence of Port-Orford-cedar on land types identified in the Soil Resource Inventory, Siskiyou National Forest

Bedrock type	Siskiyou Mountains	Klamath Mountains		Total
		Crest or east slope	West slope or north portion	
Gabbro and Metagabbro	1/ 2/3	0/4	1/4	3/11
Dacite and Rhyollite			2/4	2/4
Ultramatic		0/5	4/4	4/9
Sandstones and Conglomerates	0/2		9/17	9/19
Colebrooke Schist			2/2	2/2
Gneiss		1/3		1/3
Metavolcanics and Metasediments	3/3	0/4	4/5	7/12
Diorites and related rocks	- - - 4/5 - - -		4/4	8/9
Totals 2/	9/13	5/21	26/40	

1/ Data are no. of types with the species/total no. of types.

2/ Port-Orford-cedar also occurs on land slump topography on all types of bedrock and on 6 of 10 landtypes on deep soils with mixed or undifferentiated origin.

Source: Meyer and Amaranthus 1979.

The Soil Resource Inventory for the Siskiyou National Forest (Meyer and Amaranthus 1979) includes a list of species that grow on each general soil type. Port-Orford-cedar is listed as present on 46 of 82 land types, although no indication of its importance is given. On the west slope of the Klamath Mountains and in the Oregon Coast Range at the north end of the forest, the species is more versatile (table 12) than on inland slopes. Some information contradicts Hawk (1977) and Whittaker (1960), who found the species inland on both ultramafic rocks and gabbro (it is not listed there in table 12). It is present on inland ultramafics, however, only where seepage is consistent—probably a very small proportion of the land type represented. Ultramafic soils in the northern Klamath Mountains have been described by Rai and others (1970).

Table 13—Soil series that support >1 percent of the occurrences of Port-Orford-cedar, northern California Coast Ranges

			Surface soil	
Rock type		Series name	Texture	pH
Serpentine	*	Dubakella	Gravelly-stony loam	Neutral
Ultrabasic igneous		Cornutt	Clay loam	Slightly acid
		Dubakella	Loam	Neutral
	*	Weitchpec	Gravelly-very gravelly loam	Moderately acid
Metamorphosed basic igneous		Boomer	Loam-gravelly loam	Slightly acid
	*	Hostler	Gravelly loam	Moderately acid
	*	Neuns	Gravelly sandy loam	Moderately acid
		(Unnamed)	Clay loam	Slightly acid
Schistose sedimentary		Josephine	Loam-gravelly loam	Slightly acid
	*	Masterson	Loam	Moderately acid
	*	Orick	Loam	Moderately acid
		Sheetiron	Gravelly loam	Moderately acid
Sandstone and shale	*	Hugo	Gravelly loam	Slightly acid
		Josephine	Loam	Slightly acid
		Melbourne	Loam	Moderately acid
Soft sedimentary rock		Mendocino	Loam	Moderately acid

* = most consistently associated with Port-Orford-cedar.

Source: USDA Forest Service and others 1960-1962.

The Soil-Vegetation Maps of California (U.S. Department of Agriculture and others 1960-62) provide information about relative importance of various species on soil mapping units and briefly describe the soils for the area west of Hoopa Valley and along the lower Klamath River (table 13). In the Orleans Ranger District, Six Rivers National Forest, just to the east, Port-Orford-cedar is present on deeper phases of Hugo, Sheetiron, and Josephine soils, all on metamorphosed sediments of the Galice formation (Sawyer 1980, Sawyer and others 1977). On schistose and sedimentary parent materials in this area, Port-Orford-cedar is most common on soils of an intermediate degree of development (Hugo, Masterson, and Orick series, table 13) (Sawyer 1980, Zinke and Colwell 1965), which tend to occupy midslope positions. It also occurs, usually on lower slopes, on the little-developed Sheetiron and the better developed Josephine series. In this area, phosphorus concentration in subsoil is lowest on soils of an intermediate stage of development (Zinke and Colwell 1965)—those soils on which the cedar most often occurs.

Some lowland soils are described for coastal Curry (Buzzard and Bowlsby 1970) and Josephine Counties, OR (USDA Soil Conservation Service and Oregon Agricultural Experiment Station 1972).

Port-Orford-cedar has been grown with varying success on several soil types in Europe (Boullard 1974, Camus 1914, Macdonald and others 1957, Schenck 1907, Zehetmayer 1954). Peat mixtures are suitable for growth of potted specimens (Besford and Deen 1977, Meneve and others 1971).

Port-Orford-cedar is considered to be a suitable tree to grow on 8 of 15 woodland soil groups in western Curry County, OR (Buzzard and Bowlsby 1970), even though the tree is not common on these soils in southern Curry County. Suitable soils include those on marine terraces and on schistose and sedimentary bedrock (which cover 80 percent of the study area), those that range from 4.5 to 6.0 pH, and those with both shallow and deep water tables; included are Spodosols, Utisols, and Inceptisols.

Chemical analysis.—Chemical analyses are available for several soil types that support Port-Orford-cedar (table 14). They vary widely: pH ranges from strongly acid (on Blacklock soils) to neutral (Dubakella Series, table 13) with nutrient concentrations varying from eightfold to over 100-fold. Ultramafic soils have generally low nutrient levels (except for high levels of magnesium [Mg]) as do some other soils where cedar grows (table 14). Availability of nitrogen (N) in soils that support Port-Orford-cedar appears to be lower than in coastal soils farther north in Oregon (Imper and Zobel 1983, Plocher 1977). Cedar may, conversely, be excluded from some soils with low availability of Mg (Imper and Zobel 1983).

Chemical attributes of soils vary seasonally: pH varied by 0.4-0.8 units between September (highest) and January (lowest) (Imper 1981). pH of fine litter was 4.3 to 5.3 in July and about 0.4 units higher in January. Total N concentration in the surface mineral soil and concentrations of nitrate nitrogen (NO_3-N) also varied with season.

Imper (1981) studied the form of N, the capacity of the soil to mineralize N, and other properties of soils under Port-Orford-cedar at five sites in the valley of the South Fork Coquille River. The moisture equivalent (which estimates the percent of water in the soil at field capacity) was 24 to 46 (median = 30); fine litter mass was 0.5 to 2.3 t/ha (for three plots); and loss on ignition (estimating percent of organic matter) was 9 to 19 percent (12) in July and 7 to 18 percent (10) in September. Total N in mineral soil (0-10 cm) ranged from 0.10 to 0.32 percent, with three plots not exceeding 0.15. Extractable ammonium nitrogen (NH_4-N) in mineral soil was higher than NO_3-N by 1.7- to 17-fold, with NH_4-N varying from 2.2 to 4.1 p/m (parts per million) in July and 1.1 to 2.6 p/m in January; concentrations in the fine litter were 3-10 times higher. Both ammonium and nitrate in the soil declined from July to January. Incubations of soil and litter showed a range of response (table 15).

The capacity for N-mineralization of the topsoil was greater than that of the fine litter; however, per unit of dry weight, rates were higher in the litter. Mineralization was less in winter than in summer. Imper's (1981) sampling also illustrates that cedar distribution and soil properties vary with the microtopography within relatively small stands.

Table 14—Soil chemical properties for surface mineral soils of Port-Orford-cedar stands or for soil types that support Port-Orford-cedar within their range (although probably not where sampled)

Parent material	Type 1/	Number of stands	Reference 2/	pH	Cation exchange capacity	N	P	Extractable K	Extractable Ca	Extractable Mg	Ca:Mg ratio
						percent	- - - - p/m - - - -		- - - me/100 g - - -		
Ultramafic	Stand	1	2	6.3	--	0.12	4	72	1.6	9.9	0.16
	Soil	8	4	5.8-7.0 3/ (6.5)	10-42 (26)	--	3-8 (6)	22-149 (70)	1.0-8.0 (2.5)	1.1-29.0 (18.4)	0.09-2.3 (0.16)
	Soil	1	5	6.5	21	--	--	47	3.3	13.0	0.25
Basalt	Stand	1	1	--	--	--	--	50	.85	.42	2.0
Olivine gabbro	Soil	1	5	6.0	32	--	--	188	7.9	2.6	3.0
Quartz diorite	Soil	1	5	5.8	22	--	--	219	9.8	2.6	3.8
Eocene and Recent sedimentary	Stand	5	1	4/ 4.6-5.1 (4.8)		5/ .12-32 (.14)	2-16 (8)	60-150 (130)	.7-10.6 (2.0)	.3-1.9 (1.0)	1.4-4.3 (2.5)
	Stand	1	2	5.2	--	.24	40	400	10.8	2.9	3.7
Jurassic sedimentary	Soil	1	6	5.1	31	.37	--	50	2.3	2.2	1.1
Marine sedimentary	Stand	1	2	4.2	--	.09	26	36	.4	.36	1.1
(Blacklock)	Soil	1	6	5.1	36	.52	--	75	3.2	1.2	2.7
Dune sand	Stand	1	2	5.1	--	.03	30	36	.3	.16	1.9
Mixed deep colluvium	Soil	6	3	5.2-6.0 (5.5)	21-40 (25)	--	43 (1 sample)	40-456 (55)	4-13.9 (10.5)	.9-5.5 (4.3)	2.4-4.4 (2.6)
Several	Soil	5	3	4.9-6.4 (5.7)	22-33 (27)	.15-.17 (2 only)	7-77 (27)	36-490 (330)	1.2-15.9 (5.3)	.2-3.4 (1.9)	2.6-12.2 (2.8)
Unspecified	Stand	5	7	4.8-5.5	--	--	12-75	--	.7-14.0	6/	--

-- = no data available; me/100 g = milliequivalents per 100 grams.

1/ Stand = sites with Port-orford-cedar; soil = soil types on which cedar grows in some areas.

2/ References are: 1--Imper and Zobel (1983) and Imper (1981); 2--Plocher (1977); 3--Meyer and Amaranthus (1979); 4--Rai and others (1970); 5--Whittaker (1960); 6--Buzzard and Bowlsby (1970); 7--Siemens (1972).

3/ Values in parentheses are the median for the number of stands.

4/ pH values for September.

5/ Mean values for three sampling dates for N.

6/ Very low" to "high."

Table 15—Theoretical contribution of N-mineralization to the available nitrogen pool as ammonium or nitrate during incubation at 28 °C for 5 weeks

(In grams per square meter)

Sample site	Fine litter	Top 10 cm of soil
Coquille River Falls Research Natural Area	0.11	1.9
Ash Swamp (sample 1)	.21	4.7
Ash Swamp (sample 2)	.38	12.3
Squaw Lake	.38	3.7
Port-Orford-Cedar Research Natural Area	ND	10.4

ND = not determined.

Source: Imper 1981.

Table 16—pH of leaves, litter, and soil (averaged over the rooting depth) under Port-Orford-cedar and associated conifers in plantations in Great Britian

Species	I pH of leaves and new litter	II pH at Bedgebury			III Soil pH		
		Fresh leaves	Litter	F + H layers 1/	fledgebury	Gwydyr	Cirencester
Cupressaceae:							
Port-Orford-cedar	5.1	5.5	5.6	5.0	2/ 4.3	2/ 5.3	2/ 7.8
Western redcedar	5.1	5.5	5.4	4.8	4.3	5.1	7.7
Incense cedar	5.0	--	--	--	--	--	--
Pinaceae:							
Western hemlock	3.9	4.1	4.9	4.6	4.0	4.8	--
Douglas-fir	4.0-4.1	3.9	5.0	4.9	4.1	4.9	--
Grand fir and noble fir	--	--	--	--	--	4.9	--
Sitka spruce	--	--	--	--	--	--	7.4

-- = no data available.

1/ F + H = total of fermentation and humus layers.

2/ Includes Alaska-cedar in at least some plots.

Source: Column I--Handley 1954; II--Ovington 1953; III--Ovington and Madgwick 1957.

Relationships to growth.—Ten-year basal area growth in Imper's (1981) stands was related to 23 soil variables by regression analysis, after removing the effects of tree age. Growth of Port-Orford-cedar was significantly higher where nitrate concentration was higher ($R^2 = 0.30$); in contrast, western redcedar grew faster where calcium concentration and clay content were higher ($R^2 = 0.37$).

Characteristics of litter.—Although the forest floor is moderately shallow in most native cedar communities—I to 4 cm (Hawk 1977)—Port-Orford-cedar may have distinct effects on soil properties because of its litter characteristics. Foliage and new litter of the cedar, along with other Cupressaceae, were the least acidic of several conifers in British plantations (table 16, sections I, II): This seems to be responsible for forest plantation soils developing the highest pH under Port-Orford-cedar (table 16, section III). The relatively low acidity of the litter and soil, in contrast to the high acidity under most Pinaceae, provides a reason for maintaining or introducing Port-Orford-cedar, or cupressaceous species in general, to managed stands.

Leaves and litter differ in other ways from those of associated conifers in British plantations (table 17): under Port-Orford-cedar, N is lowest and the carbon (C) to N ratio highest throughout the forest floor. Forest floor dry weight of Port-Orford-cedar and western redcedar was higher than for that under Douglas-fir and grand fir ***(Abies** grandis* [Dougl. ex D. Don] Lindl.).

Litter of Cupressaceae differs from that of the Pinaceae in structure. The litter under cedar is composed of branchlets, not leaves (Al-Sherifi 1952), that "retain their structure within the unincorporated organic matter but are broken into smaller distinct components below and hardly any amorphous humus is present" (Ovington 1954, p. 75). In contrast, litter of grand fir, Douglas-fir, and western hemlock *(Tsuga heterophylla* [Raf.] Sarg.) decomposes rapidly at first but decay slows later, resulting in a forest floor with a thin F-layer above a dominant H-layer (Ovington 1954).

Table 17—Characteristics of fresh leaves and forest-floor layers of Port-Orford-cedar and associated conifers, 23- to 25-year-old British plantations

Species	Forest floor weight			Nitrogen content			Ratio of C to N			Ash		
	Total	Percent in litter layer	Nitrogen	Fresh leaves	Litter layer	F+H 1/	Fresh leaves	Litter layer	F+H 1/	Fresh leaves	Litter layer	F+H 1/
	kg/ha		kg/ha	- - - -	percent	- - - -				- - - -	percent	- - - -
Port-Orford-cedar	12 893	17	152	0.92	0.84	1.24	67	70	39	4.6	8.4	24.6
Western redcedar	12 131	13	180	1.22	1.20	1.52	58	49	32	4.0	6.0	22.1
Western hemlock	12 160	63	188	1.48	1.20	1.76	40	48	26	3.5	8.3	26.1
Douglas-fir	10 931	24	156	1.27	1.29	1.46	48	44	27	4.7	20.3	36.2
Grand fir	6 592	28	--	--	--	--	--	--	--	--	--	--

-- = no data available.

1/ F + H = total of fermentation and humus layers.

Source: Ovington 1954.

Chapter 4: Forest Types

Distribution Through Geologic Time

The fossil record for Cupressaceae is rich but hard to interpret because of difficulties identifying their leafy shoots. The genus ***Charnaecyparis*** seems to have been more widespread during the Tertiary than at present; it occurred in southern and central Europe and in western Asia between the Paleocene and the Pliocene (65 to 2 million years ago) (Florin 1963) and perhaps in western Europe in early Pleistocene (Huckerly and Oldfield 1976). The record of supposed ***Charnaecyparis*** fossils is most extensive in western North America (Axelrod 1976a, 1976b; Edwards 1983; Wolfe 1969) with the oldest found in the Eocene (50 to 52 million years ago) in Wyoming (MacGinitie 1974). Most interpretations (for example, Axelrod 1966, 1976a, 1976b; Robichaux and Taylor 1977) conclude that ancestors of Port-Orford-cedar dominated the North American record for the genus, although Wolfe (1969) dissents and identifies Alaska-cedar (***C. nootkatensis*** [D. Don] Spach) from several locations in Nevada. An extensive, detailed study of foliar morphology of living and fossil Cupressaceae led Edwards (1983) to conclusions at variance with many earlier reports. He identified ***Charnaecyparis*** from about three dozen fossil locations in North America with deposits about 10 to 52 million years old. Several phylogenetic lines were suggested, one leading to Port-Orford-cedar and the related ***C. linguaefolia*** (Lesq.) MacGinitie at Florissant in central Colorado (MacGinitie 1953); one to Atlantic white-cedar (***C. thyoides*** [L.] B.S.P.); but with the majority, including the widespread ***C. cordillerae*** Edwards & Schorn, being more closely related to Alaska-cedar. Fossils apparently ancestral to Port-Orford-cedar occur at Metzel Ranch (southwestern Montana, late Eocene); Gumboot Mountain and Lyons (northwestern Oregon, the latter 30 to 32 million years ago); Clarkia (northern Idaho, 14 million); Kilgore (north-central Nebraska, the easternmost ***Chamaecyparis*** location); Hidden Lake (northwestern Oregon, 13 million); and Trapper Creek (southeastern Idaho, 11-12 million) (Edwards 1983).

These populations are not associated with ultramafic substrates in most cases, but appear to have grown in streamside habitats (Edwards 1983). The associated climate had rainfall estimated at about 640-2030 mm (mostly 1010-1270 mm) and evenly distributed throughout the year. Paleotemperatures vary drastically with the method used to estimate them (Edwards 1983); however, the best estimates of mean annual temperatures are 7-12 °C, with mean annual ranges of 16-25 °C for taxa ancestral to Port-Orford-cedar. The lineage appears to have always been associated with relatively mild winter climates.

The fossil floras that include ancestors of Port-Orford-cedar differ from modern vegetation and vary substantially from place to place. Some forests had primarily broad-leaved species, and at two sites *Chamaecyparis* was the only conifer macrofossil; relatives of Alaska-cedar grew in more conifer-rich vegetation. The Hidden Lake flora, however, including taxa related to both Alaska-cedar and Port-Orford-cedar, contained the “most diverse conifer assemblage known in the history of the planet” (Edwards 1983, p. 198) with 16 genera. Comparisons of past and present ranges, environments, and associated taxa led Edwards (1983) to conclude that ecological tolerances have changed: The present ecological amplitude of Port-Orford-cedar reflects the concentration of genetically based characteristics in a small area that had developed in a much larger former geographic range.

In the range of Port-Orford-cedar, where there is relatively high humidity in the summer and a moderate range of temperature, conditions provided a refuge for mesophytic species beginning in the Pliocene (Axelrod 1976a, Whittaker 1961, Wolfe 1969). Port-Orford-cedar is considered a local but vigorous relict (Cain 1944). Pleistocene forests of the Klamath Mountains apparently occurred at lower elevations (Whittaker 1961); temperatures in northern California were 6-8 °C cooler and rainfall was considerably greater between 13,000 and 75,000 years ago than at present (Adam and West 1983). The interior California population of *Chamaecyparis* could be descendants of earlier interior stands, which spread out at lower elevations during cooler, moister climates, and reinvaded the high elevations after the last glacial retreat (see footnote 3); alternatively, the populations could have originated after the species migrated across the intervening low-elevation areas from the coast during the Pleistocene.

Forest Types and Their Distribution

With its small range and scattered distribution, Port-Orford-cedar is not usually considered in large-scale vegetation classifications. Küchler’s (1964) map of the United States lists it only for the southern part of his “spruce-cedar-hemlock forest”; for the map of California he includes it only for the northern part of the “redwood forest” and in the “mixed evergreen forest with chinquapin” (Küchler 1977). It is recorded as a dominant in the Port-Orford-cedar forest cover type (Eyre 1980) and as present in the Sitka spruce, Pacific Douglas-fir, Redwood, Oregon white oak, and Douglas-fir-tanoak-Pacific madrone forest cover types.

Regional studies report Port-Orford-cedar in several vegetation zones. In Oregon, it grows in the *“Picea sitchensis* zone” and the “mixed evergreen zone,” and its presence is used to define the “Port-Orford-cedar variant” of the *“Tsuga heterophylla* zone” by Franklin and Dyrness (1973). It is also a component of their *“Abies concolor* zone” (Hawk 1977, Atzet 1979). In southern Josephine County, OR, Atzet (1979) recognized a separate *“Chamaecyparis lawsoniana* Zone,” which has been modified to a *“Chamaecyparis lawsoniana* series” following a more extensive sampling of southwestern Oregon? In California, Port-Orford-cedar occurs in “redwood forest” (Zinke 1977), “mixed evergreen forest” (Sawyer and others 1977), and both the *Abies concolor* and *Abies magnifica* zones of the “Montane and subalpine forest” (Sawyer and Thronburgh 1977).

Several detailed vegetation analyses have been done in the range of Port-Orford-cedar. Hawk (1977) recognized eight major communities in well-developed cedar forests (tables 18 to 22). Characteristics of Port-Orford-cedar forests are discussed below, from north to south, based on the vegetation zone classification of Franklin and Dyrness (1973) and the communities recognized by Hawk (1977).

Picea sitchensis zone.—The northern limit of Port-Orford-cedar seems to occur on coastal dunes, but landscape planting along the coast has been so general that the limit cannot be accurately located now. Boardman (1954) says the natural limit along U.S. Highway 101 was 13 km north of North Bend, which is near Hawk’s (1977) Saunders Lake population on dry dunes. Port-Orford-cedar occurs in both dry and wet sand dunes (Egler 1934, Hawk 1977, Sargent 1881) along with shore pine *(Pinus contorta* Dougl. ex Loud. var. *contorta),* Douglas-fir, western hemlock (Hawk 1977), and typical dune associates (Egler 1934, Wiedemann and others 1969). It is not common in the dunes, however, and contrary to Sargent’s (1896) “sea beach” statement, does not seem to grow well on the immediate coast. North of Coos Bay, the tree also grows profusely along roadsides and in stands off the dunes—stands apparently similar to those south of the bay. Some of the northern-most inland populations are limited to ridgetops and north-facing cliffs with open forests.

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[4] Personal communication, 1981, T. Atzet, Area Ecologist, USDA Forest Service, Grants Pass, Oregon.

Table 18—Cover and diversity in eight major forest communities dominated by Port-Orford-cedar

		Cover by stratum 1/					Species per 375-m^2 plot		
		Trees							
Zone	Community (number of plots)	>15 cm d.b.h.	≤ 15 cm d.b.h.	Shrub	Herb	Moss	Trees	Shrub	Herb
		Percent					Number		
Tsuga heterophylla	Swordfern (13)	83	46	9	60	39	5	7	18
	Rhododendron (6)	84	33	91	24	40	5	9	13
	Beargrass (12)	85	30	30	25	45	5	6	11
Mixed evergreen	Tanoak (16)	80	37	97	8	19	5	11	14
	Mixed pine (11)	39	34	ti7	27	6	5	11	20
Abies concolor	White fir-hemlock (10)	86	30	50	16	7	7	10	16
	White fir (15)	77	37	40	20	1	5	10	27
	Mixed fir (15)	75	43	38	23	4	5	10	25

1/ "Tree cover" is an estimate for the whole layer; shrub, herb, and moss covers are totals for all species, counting overlapped areas for each overlapping species.

Source: Hawk 1977.

Table 19—Tree density, relative importance of Port-Orford-cedar, and size of Port-Orford-cedar in mature forests (>200 years) of eight major forest communities

		Trees > 15 cm d.b.h.			Basal area		Conifer saplings and seedlings		Size of Port-Orford-Cedar	
Zone	Community and number of mature stands	Total	Conifer	Port-Orford-cedar	Total	Port-Orford-cedar	Total	Port-Orford-cedar	Basal area per tree	Height at 300 years
		number per ha		percent	m^2/ha	percent	number per ha	percent	m^2	m
Tsuga heterophylla	Swordfern (11)	342	304	38	121	63	2024	26	0.58	63
	Rhododendron (4)	313	313	63	144	47	1246	39	.34	53
	Beargrass (9)	497	485	55	150	68	1781	55	.37	31
Mixed evergreen	Tanoak (12)	389	371	74	150	60	2115	78	.31	44
	Mixed pine (3)	285	285	47	30	63	1867	24	.14	29
Abies concolor	White fir-hemlock (10)	464	415	48	83	55	1995	32	.21	41
	White fir (7)	674	670	82	139	63	4113	47	.16	46
	Mixed fir (12)	396	367	46	114	58	2207	37	.36	50

Source: Hawk 1977.

Table 20—Tree species and their degree of importance in the overstory and understory in eight major Port-Orford-cedar forest communities[1/] [2/]

Zone:	Tsuga heterophylla			Mixed evergreen		Abies concolor		
Species / Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
Abies concolor	--	--	--	--	mo	Mou	Mou	Mou
Abies grandis	mou	mou	--	--	--	--	--	--
Abies magnifica var. shastensis 3/	--	--	--	--	--	--	mou	mou
Acer macrophyllum	mu	mu	--	--	--	--	--	--
Alnus rubra	mu	mu	--	--	--	mu	--	--
Arbutus menziesii	--	mu	--	mu	mo	--	--	--
Calocedrus decurrens	--	--	--	--	mo	--	mo	mo
Castanopsis chrysophylla	--	--	--	Mu	--	mu	--	Mu
Castanopsis sempervirens	--	--	--	--	--	--	--	mu
Chamaecyparis lawsoniana	Mou	Mou	Mou	Mou	Mou	Mou	Mou	Mou
Chamaecyparis nootkatensis	--	--	--	--	--	--	--	mou
Lithocarpus densiflora	mu	mu	Mu	Mou	mu	mu	mu	mu
Picea breweriana	--	--	--	--	mou	--	--	--
Pinus attenuata	--	--	--	--	mou	--	--	--
Pinus jeffreyi	--	--	--	--	Mou	--	mo	--
Pinus lambertiana	--	mo	--	mo	mu	mo	mo	mou
Pinus monticola	--	--	mo	mo	Mou	--	mo	--
Pinus ponderosa	--	--	--	--	Mou	--	mo	--
Pseudotsuga menziesii	Mo	Mo	Mo	Mou	Mou	Mo	Mo	Mo
Quercus chrysolepis	--	--	mu	mu	mu	--	mu	--
Taxus brevifolia	mu	mu	mu	mu	--	Mu	mu	mu
Thuja plicata	mo	--	--			Mou	--	--
Tsuga heterophylla	Mou	Mou	Mou	--	--	Mou	--	--
Tsuga mertensiana	--	--	--	--	--	--	--	mo

-- = absent.

1/ M = major; m = minor; o = overstory; u = understory.

2/ Tree species associated in other vegetation types are Picea sitchensis, Pinus contorta, Quercus garryanna, Q. kelloggii, and Sequoia sempervirens.

3/ Also considered to be A. procera by some authors.

Source: Hawk 1977.

Table 21—Major shrub species associated with Port-Orford-cedar in eight major forest communities[1]

Zone:	Tsuga heterophylla			Mixed evergreen		Abies concolor		
Species / Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
Acer circinatum	--	M	--	--	--	--		
Alnus rhombifolia	--	--	--	--	--	--	m	--
Arctostaphylos nevadensis	--	--	--	--	M	--		
Berberis nervosa	m	M	m	m	--	m	m	M
Castanopsis chrysophylla	--	--	--	M	--	--	--	M
Ceanothus pumilus	--	--	--	--	M	--	--	--
Corylus cornuta	--	m	--	--	--	--	--	--
Gaultheria ovatifolia	--	--	--	--	--	--	m	m
Gaultheria shallon	m	M	M	M	--	--	--	--
Holodiscus discolor	--	m	--	--	m	--	M	--
Leucothoe davisiae	--	--	--	--	--	M	--	--
Lithocarpus densiflora	m	M	M	M	m	m	m	m
Quercus sadleriana	--	--	--	m	--	M	M	M
Quercus vaccinifolia	--	--	--	m	M	m	m	--
Rhamnus californica	--	--	--	m	M	--	--	--
Rhododendron macrophyllum	m	M	M	M	--	M	M	M
Rhododendron occidentale	--	--	m	M	M	--	M	--
Rosa gymnocarpa	--	m	m	m	m	m	m	m
Umbellularia californica	--	m	--	M	m	--	--	--
Vaccinium membranaceum	--	--	--	--	--	--	m	m
Vaccinium ovatum	m	M	M	M	--	--	--	--
Vaccinium parvifolium	m	m	m	m	M	m	m	M

-- - absent.

1/ M = major species (≥ 2 percent cover); m = minor (≤ 2 percent cover). Only species with ≥ 2 percent cover in at least one community are listed.

Source: Hawk 1977.

Table 22—Most important herbaceous species in eight major Port-Orford-cedar forest communities1/

Zone:	Tsuga heterophylla			Mixed evergreen			Abies concolor	
Species / Community:	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
Achlys triphylla	--	--	--	--	--	--	M	M
Adenocaulon bicolor	m	m	--	--	--	m	m	m
Anemone deltoidea	m	--	--	--	--	--	m	m
Athyrium filix-femina	--	m	--	--	--	--	m	m
Blechnum spicant	m	M	--	--	--	--	--	--
Carex serratodens	--	--	--	m	m	--	--	--
Chimaphila menziesii	--	m	m	--	m	m	m	--
Chimaphila umbellata	--	m	m	m	--	m	m	m
Clintonia uniflora	--	--	--	--	--	m	m	--
Disporum hookeri	m	m	m	m	--	m	m	m
Galium ambiguum	--	--	m	m	m	--	--	--
Galium triflorum	m	m	m	--	--	--	m	m
Goodyera oblongifolia	m	m	m	m	m	m	m	m
Iris innominata	--	--	m	m	m	--	m	--
Linnaea borealis	m	--	m	m	--	M	M	M
Osmorhiza chilensis	--	--	--	--	--	--	m	m
Oxalis oregana	M	M	--	--	--	--	--	--
Polystichum munitum	M	M	M	M	--	m	m	m
Pteridium aquilinum	m	m	--	m	--	m	m	m
Syntneris reniformis	--	--	m	m	--	m	m	--
Tiarella unifoliata	m	m	--	--	--	m	m	m
Trientalis latifolia	m	m	m	m	m	m	m	m
Trillium ovatum	m	m	m	m	--	m	m	m
Trillium rivale	--	--	m	m	m	--	m	--
Vancouveria planipetala or V. hexandra	m	m	m	m	--	--	m	m
Viola glabella	--	--	--	--	--	--	m	m
Viola sempervirens	M	m	m	m	--	--	m	m
Whipplea modesta	m	m	m	m	m	m	m	--
Xerophyllum tenax	--	--	M	m	M	m	M	--
Others	--	--	2/	--	2/	2/	2/	2/

1/ M = ≥ 1 percent cover; m = ≤ 1 percent cover, -- = absent.

2/ The following species occur only in one community: Beargrass: Coptis laciniata (m), Senacio bolanderi (m); Mixed pine: Festuca californica (M), Gentiana affinis (m), Horkelia sericata (m), Microseria nutans (m), Senecio canus (M), and Viola cuneatus (m); White fir-hemlock: Lysichiton americanum (m); White fir: Elymus glauca (M) Streptopus amplexifolius (m); Mixed fir: Pyrola secunda (m).

Source: Hawk 1977.

The best developed original forests of Port-Orford-cedar were near the coast in southern Coos and northern Curry Counties (fig. 8). Exploitation, major forest fires in 1867, 1868 (Hermann 1924, Sargent 1881), and 1936, and more recently, Port-Orford-cedar root rot, have apparently eliminated the old-growth forests. The first descriptions of these forests were by early travelers (Oregon Historical Records Survey 1942), by Beardsley (in Kellogg [1857]; also see appendix), and by Sargent (1881, summarized in 1884, 1896). On the hill behind Empire, on the west side of the peninsula south and west of Coos Bay, forests of Douglas-fir and Port-Orford-cedar had a thick, dense understory of *Rhododendron macrophyllum* up to 8 m tall. Near Marshfield, at the head of the bay, the forest

> . . . is very dense and heavy, consisting of Douglas-fir, the western hemlock, *Thuya gigantea* [western redcedar], *Abies grandis* [grand fir], the 'Tide-water Spruce' [Sitka spruce], and Lawson's Cypress [Port-Orford-cedar]. It is the most beautiful forest we have seen. The undergrowth is very luxuriant. Rhamnus Purshiana is here a common tree, 40-50 feet high and over 1 foot in diameter. The Rhododendron has disappeared, but the Solomon Berry, the various Vaccinia, and the Roses, so characteristic of the Oregon forests, attain a size here we have not seen before. Pteris aquilina *[Pteridium aquilinum* (L.) Kuhn] reaches above our heads as we force our way through it. This forest gives a greater idea of productive capacity than any we have seen. No other coniferous forest on the continent compares with it in beauty, in grace, or in variety. Here Lawson's Cypress grows to a height of more than 150 feet, with a diameter of trunk of 8-10 feet. The trunks of these old trees are bare of branches for a great part of their height, and the heads are neither large nor very striking. The bark is remarkable on account of its thickness, being sometimes more than one foot thick on the old trees—a curiosity among the Cupressineae. . . .
>
> The heaviest continuous body of Port-Orford-cedar is on Cape Gregory, extending south to and beyond the mouth of the Coquille [River]. This belt is about 20 miles long by an average width of 12 miles, and lies along the western slopes of the foothills of the coast range, extending within 3 miles of the coast. In this belt, two-thirds of the trees are cedar, the other Tidewater Spruce *(Picea sitchensis),* with a few Douglas-fir (Sargent 1881, p. 8).

The importance of cedar in these forests appears to have been considerably overestimated in the early descriptions, however (see cruise data presented on page 42 and in Chapter 8). This area is the low hills and uplifted marine terraces between the Coquille River-Coos Bay trough and the sea on primarily Coaledo formation sandstone and Quaternary alluvium and terrace deposits (Baldwin and others 1973); Sargent (1881) described the sites as "rather dry sandy ridges." Port-Orford-cedar was most abundant on the western slopes (Walling 1884). Old-growth forests were also present on river terraces (Dion 1938) and along the coast south to Port Orford in Curry County, where there were "immense white cedar forests so near the town" (Hermann 1924, p. 321).

Figure 8.—Old-growth Port-Orford-cedar forest in northern coastal Curry County, OR, 1911 (from American Lumberman 1911). The tree on the right is a Douglas-fir.

Many second-growth stands in this area burned in 1936 (Dion 1938), and root rot has decimated most of the rest. Port-Orford-cedar is present throughout much of this area, but the young forests have been little described. Cedar is not a major forest component near Blacklock Point in northern Curry County (Martin and Frenkel 1978), although it was a dominant just inland where the Curry County Airport is now located (Boardman 1954) on a Blacklock fine sandy loam (Buzzard and Bowlsby 1970).

Hawk (1977) describes two communities of limited extent in this area. The "Sandstone" community is thought to be descended from the forests described by Sargent. It is dominated by Port-Orford-cedar and Sitka spruce *(Picea sitchensis* [Bong.] Carr.) with occasional Douglas-fir and western hemlock. The two 65-year-old plots sampled support little understory vegetation, although older forests resemble those in the swordfern community inland (except for presence of spruce). The "Blacklock" community occurs on uplifted marine terraces on the poorly drained Blacklock soil series with an iron hardpan (Jenny and others 1969). Port-Orford-cedar, western hemlock, and Sitka spruce are small and grow slowly; tree reproduction is dense, as is the shrub layer, which is dominated by evergreen huckleberry *(Vaccinium ovatum* Pursh), salal *(Gaultheria shallon* Pursh), and wax myrtle (*Myrica californica* Cham.) (Hawk 1977).

Tsuga heterophylla zone.—Much of the present commercial forest lies within and bordering the drainages of the East Fork, the Middle Fork, and especially the South Fork Coquille River, south and inland from Coos Bay, OR. Three of Hawk's (1977) communities (tables 18 to 22) occur primarily in this area:

1. The swordfern community *(Tsuga heterophylla-Chamaecyparis lawsoniana/Polystichum munitum-Oxalis oregana* community of Hawk [1977]) occurs on the most productive sites sampled—the more mesic areas on sedimentary (mostly Eocene) rocks. Port-Orford-cedar and Douglas-fir dominate the overstory; western hemlock is abundant but the trees are small. Tree reproduction is common; it is dominated by western hemlock, and Port-Orford-cedar are plentiful. The shrub layer is the least important and the herbaceous layer the most important of all Port-Orford-cedar communities; the latter is dominated by swordfern *(Polystichum munitum* Kaulf. Presl.) and oxalis *(Oxalis oregana* Nutt.).

2. On less mesic sites on sedimentary rocks, the rhododendron community *(Tsuga heterophylla-Chamaecyparis lawsoniana/Rhododendron macrophyllum-Gaultheria shallon* community) occurs. Tree dominance is similar to the swordfern community, with Port-Orford-cedar, Douglas-fir, and western hemlock; conifer reproduction is much less dense and Douglas-fir is well represented along with the other two. The tall, dense shrub layer is dominated by rhododendron *(Rhododendron macrophyllum G.* Don) and salal and 10 percent of shrub cover is deciduous species. Herbaceous coverage, dominated by swordfern, is less than half that of the swordfern community.

3. The beargrass community *(Chamaecyparis lawsoniana-Tsuga heterophylla/Xerophyllum tenax* community) occurs on ultramafic rocks. The overstory is again dominated by Port-Orford-cedar, Douglas-fir, and western hemlock with some sugar pine *(Pinus lambertiana* Dougl.). Tree reproduction is primarily Port-Orford-cedar and western hemlock. The shrub layer is variable but the rhododendron is dominant. Beargrass *(Xerophyllum tenax* [Pursh] Nutt.) is the major herbaceous species. At higher elevations than those sampled by Hawk, western white pine *(Pinus monticola* Dougl. ex D. Don) can dominate the reproduction, and lodgepole pine is locally important.

Atzet (see footnote 4) recognizes one community ***(Tsuga heterophylla-Chamaecyparis lawsoniana/Rhododendron macrophyllum-Gaultheria shallon/Polystichum munitum)*** in his ***Tsuga heterophylla*** series, which appears to incorporate the three communities described above. Several other authors describe stands in the Coquille River drainage. Near the South Fork Coquille River, eight stands with Port-Orford-cedar, including six with western redcedar, can be classified in the swordfern community (Imper 1981). The association with western redcedar is not common, however. The Port-Orford-Cedar and Coquille River Falls Research Natural Areas include stands from all three communities (Franklin and others 1972, sections CO and PO). Contrary to Hawk's (1977) conclusion, Franklin and others (1972) state that western hemlock is reproducing much more effectively than is Port-Orford-cedar (see Chapter 6).

Other stands in the ***Tsuga heterophylla*** zone recur in and just east of the redwood belt in coastal northern California; these are a "Tsuga phase" of mixed evergreen forest (Sawyer and others 1977). Along the lower Klamath River, 16 percent of the vegetation units in which Port-Orford-cedar is the first or second most important species include hemlock, along with Douglas-fir and tanoak. Hemlock occurs with Port-Orford-cedar in many other stands (but not a majority) in the same area; all are on sedimentary and schistose sedimentary rocks (U.S. Department of Agriculture and others 1960-1962).

Port-Orford-cedar occasionally grows with redwood ***(Sequoia sempervirens*** [D. Don] Endl.) along the lower Klamath River (Hawk 1977, U.S. Department of Agriculture and others 1960-62) and Smith River (Hawk 1977, Zinke 1977), and their tributaries; Douglas-fir and western hemlock also occur in these stands.

Mixed evergreen zone.—Most low-elevation stands south of the Coquille River drainage and outside the range of redwood are in this zone in which broad-leaved evergreen trees are important. Two major communities are found (Hawk 1977), usually on ultramafic rocks (tables 18 to 22):

1. Tanoak community ***(Chamaecyparis lawsoniana/Lithocarpus densiflora*** community) occupies the more mesic locations. Port-Orford-cedar dominates both overstory and tree reproduction, with considerable Douglas-fir, tanoak ***(Lithocarpus densiflorus*** [Hook. & Arn.] Rehd.), and some pines. Shrub cover is almost complete; tanoak, salal, rhododendron, and azalea ***(Rhododendron occidentale*** [T. & G.] Gray) are all important. Herbaceous cover is the lowest of Hawk's communities at 8 percent.

2. Mixed pine community (***Pinus-Chamaecyparis lawsoniana/Quercus vaccinifolia/ Xerphyllum tenax*** community) occurs as open forest on less favorable sites. It occupies a large range of elevations but is most common in this zone. The open canopy is dominated by Port-Orford-cedar, with Jeffrey pine ***(Pinus jeffreyi*** Grev. & Balf.) a distant second; Douglas-fir, western white pine, and sugar pine are common in some stands. Pines, Port-Orford-cedar, and Douglas-fir are all reproducing effectively. The understory is a mosaic of dense shrub clumps and open, herbaceous vegetation. The herb "phase" is more common on steeper slopes. Huckleberry oak (***Quercus vaccinifolia*** Kell.) dominates the shrub layer with California coffee berry ***(Rhamnus californica*** Esch.) and, in the wettest spots, azalea being important. The major herb is beargrass.

Two mixed evergreen zone communities are more restricted (Hawk 1977):

1. The Douglas-fir terrace community *(Chamaecyparis lawsoniana-Pseudotsuga menziesii/*foothill alluvial terrace community) occurs along some large creeks above where they enter the interior valleys. These forests range from mesic, including deciduous red alder (*Alnus rubra* Bong.) and big leaf maple *(Acer macrophyllum* Pursh) in young forests, to relatively xeric with large tanoaks. Reproduction of Port-Orford-cedar, grand fir *(Abies grandis* [Dougl. ex D. Don] Lindl.), and Douglas-fir is common. Most shrubs are deciduous, which is unusual in this zone.

2. The meadow community *(Chamaecyparis lawsoniana*/ultramafic meadow community) is really azonal on ultramafic parent material in wet, open sites along streams or in bogs. Port-Orford-cedar is often the only tree in the wet areas. Shrubs and other trees are common only on drier hummocks or ridges. The herb layer is rich and dense, dominated by sedges, lilies, iris, and orchids. Cobra-plant (*Darlingtonia californica* Torr.) is common, and several other rare and endangered species grow in these sites. Well-developed examples of the community are Hunter Creek Bog and Snow Camp Meadow (Curry County, OR), and Woodcock Bog (Josephine County, OR).

Vegetation of this zone in Oregon has also been described by Whittaker (1954, 1960), Emmingham (1973), and Atzet (1979) (see page 37). In Atzet's more extensive classification (see footnote 4), the *Lithocarpus densiflora* series includes one community with substantial Port-Orford-cedar *(Lithocarpus densiflora-Chamaecyparis lawsoniana/Gaultheria shallon-Rhododendron macrophyllum-Vaccinium ovatum).* The cedar occasionally occurs in other communities of the series.

Similar forests occur in California within the range of Port-Orford-cedar. In the mixed evergreen forests of Klamath, Del Norte, and Siskiyou Counties, Port-Orford-cedar grow on the wettest sites in ravines on ultrabasic (= ultramafic), granitic, and metamorphic parent materials (Hawk 1977, Sawyer and others 1977, Zinke 1977).

Farther south, near Orleans, CA, Port-Orford-cedar is present on deeper soils of lower slopes on metasedimentary rocks of the Galice formation. At 200-700 m on deeper soils, Douglas-fir and Port-Orford-cedar dominate in mixture with evergreen hardwoods (Sawyer 1980). The shrubby understory is dense, but reproduction of all trees is occurring. Port-Orford-cedar is smaller and rare on shallow or rocky soils. In the northern Coast Ranges of California, Port-Orford-cedar is sometimes codominant with Douglas-fir and tanoak (Sawyer and others 1977) and sometimes with sugar pine (U.S. Department of Agriculture and others 1960-1962); on moister sites, western hemlock is also present.

Abies concolor zone.—At high elevations south of the Coquille drainage, white fir ***(Abies concolor*** [Gord. & Glend.] Lindl. ex Hildebr.) is a primary, shade-tolerant conifer. Port-Orford-cedar dominates in three communites in this zone (tables 18 to 22) (Hawk 1977):

1. The white fir-hemlock community ***(Abies concolor-Tsuga heterophylla-Chamaecyparis lawsoniana*** community) is transitional between the ***Tsuga heterophylla*** and ***Abies concolor*** zones. Hawk (1977) describes it for the Silver Creek drainage in northwestern Josephine County, OR, where it occurs in ravines in a complex geologic area. Vegetation differs from any previously described, with western hemlock, white fir, and Port-Orford-cedar occurring together with Douglas-fir. All except Douglas-fir are reproducing effectively. The variable shrub layer is dominated by western leucothoe ***(Leucothoe davisiae*** Torr.). The herb layer is sparse.

2. The white fir community ***(Abies concolor-Chamaecyparis*** *lawsoniana*/herb community) is widespread on a variety of parent materials at high elevations in the southern two-thirds of the range. Port-Orford-cedar, Douglas-fir, and white fir dominate. White fir reproduction is less dense but more vigorous than Port-Orford-cedar reproduction. The shrub and herb layers are moderately well developed and diverse, and composition varies considerably.

3. The mixed fir community ***(Abies-Chamaecyparis*** *lawsoniana*/herb community) was sampled primarily on diorite in the upper Illinois River drainage in southern Josephine County, OR. Port-Orford-cedar dominates and Douglas-fir and white fir are common; Shasta red fir ***(Abies magnifica*** var. ***shastensis*** Lemm.) is often present. Tree reproduction is mostly white fir and Port-Orford-cedar with some Douglas-fir and Shasta red fir. The shrub layer is dense in young stands but decreases with age; herbaceous cover increases with age. The understory layers are diverse with no strong dominants.

Atzet's regional vegetation classification for southwestern Oregon (see footnote 4) recognizes two series in which both white fir and Port-Orford-cedar are important: (1) the ***Chamaecyparis lawsoniana*** series with four communities ***(Chamaecyparis /Berberis nervosa/Achlys triphylla, Chamaecyparis/Berberis/Linnaea borealis, Chamaecyparis/Gaultheria shallon/Linnaea,*** and ***Chamaecyparis/Quercus vaccinifolia/Arctostaphylos nevadensis);*** and ***(2)*** in two communities of the ***Abies concolor*** series where Port-Orford-cedar is usually present only in the understory.

The high-elevation Port-Orford-cedar communities in California are somewhat similar to those of southern Oregon (Sawyer and Thornburgh 1977). The tree is most common on ultrabasic rocks along with Douglas-fir and western white pine; this type is an upper elevation extension of the mixed evergreen communities. On other parent materials, the species is rare in the ***Abies concolor*** zone in California (Hawk 1977, Sawyer and Thornburgh 1977), and it is rare in open forests on rocky, damp moraines in the higher ***Abies magnifica*** zone of Sawyer and Thornburgh (1977).

Table 23—Importance of Port-Orford-cedar in forests, Preston Peak-Clear Creek area, Siskiyou County, CA

Forest type 1/	Number of transects 2/	Transects with Port-Orford-cedar	Mean: Cover, Over 3/	Mean: Cover, Under 3/	Mean: Relative density, Over 3/	Mean: Relative density, Under 3/
		Percent				
Port-Orford-cedar	3	100	42	13	56	33
Port-Orford-cedar-Douglas-fir ecotone	2	100	25	2	46	6
Douglas-fir	21	57	6	2	11	5
White pine woodland	2	50	3	3	13	5
Sugar pine	5	40	2	1	7	1
Lodgepole pine	3	67	--	2	--	2
Weeping spruce	1	100	--	t 4/	--	1

-- = absent.

1/ No Port-Orford-cedar were reported in single transects of the following forest types: weeping spruce-Douglas-fir ecotone; ponderosa pine, madrone-tanoak, Jeffrey pine, Douglas-fir-sugar pine ecotone; noble fir (Abies procera)-Douglas-fir ecotone; and noble fir. Abies procera is considered to be A. magnifica var. shastensis by some authors.

2/ Each transect line was 92-480 m long. Cover and relative density are averages for all transects where Port-Orford-cedar was present.

3/ "Over" and "under" refer to overstory and understory.

4/ t = < 0.5 percent.

Source: Siemens 1972.

Port-Orford-cedar forests in this zone are also described for the Brewer Spruce Research Natural Area (Franklin and others 1972, section BP) and for the Preston Peak area of northern California (Siemens 1972). In the Preston Peak area, Port-Orford-cedar dominates one type of montane forest. It is codominant with Douglas-fir on level sites along most stream drainages and there are a few extensive stands in basins (table 23). White fir may be common also. The understory is sparse. At higher elevations, between 1460 and 1770 m, Port-Orford-cedar grows with Alaska-cedar and western white pine.

The disjunct inland range of Port-Orford-cedar occurs primarily at high elevations (Hawk 1977, MacGinitie 1953; and footnote 5), although populations grow at least as low as 580 m along the Sacramento River in California. Near Cedar Lake, which is above 1700 m, the species grows in open, diverse forests that include Douglas-fir, white fir, mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.), five pine species, incense cedar, and a huckleberry oak understory. Port-Orford-cedar is most important, however, near lakes and streams in denser forests that have a diverse understory. Many plants from Hawk's (1977) meadow community are present. Port-Orford-cedar is reproducing effectively. In this area, it apparently reaches its maximum elevation of 1950 m (see footnote 1).

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[5] Personal communications, 1981, R. Kelly, Berkeley, California, and J.O. Sawyer, Jr., Humboldt State University, Arcata, California.

Table 24—Occurrence of Port-Orford-cedar in forest communities, upper Illinois River drainage, OR

Zone	Community name and number of samples	Elevation 1/	Total basal area	Port-Orford-cedar	
				Constancy	Cover
		meters	m^2/ha	- - percent - -	
Pinus jeffreyi	*Pinus jeffreyi*/*Festuca rubra* (9)	920-940	58	22	9
Chamaecyparis lawsoniana	*Chamaecyparis lawsoniana*/*Gaultheria shallon*/*Linnaea borealis* (10) 2/	540-1010	79	90	30
	C. lawsoniana/*Berberis nervosa*/*Chimaphila umbellata* (18) 2/	1230-1440	100	78	9
	C. lawsoniana/*Quercus vaccinifolia*/*C. umbellata* (5) 2/	1220-1560	77	80	23
Abies concolor	*Abies concolor*/*Berberis nervosa*/*C. umbellata* (9) 2/	990-1370	86	67	23
	A. concolor/*Quercus sadleriana*/*C. umbellata* (18)	1480	81	6	t 3/
	A. concolor/*Berberis nervosa*/*Achlys triphylla* (68)	1480	73	1	t 3/

1/ Elevation refers only to where the species was present.

2/ Communities of the *Chamaecyparis lawsoniana* "group."

3/ t = < 0.5 percent.

Source: Atzet 1979.

Forest patterns in the Illinois Valley, OR.—The montane forest vegetation of the Illinois River drainage has been described in detail using classification procedures for National Forest land (Atzet 1979, Emmingham 1973) and gradient analysis on three intrusive rock types (Whittaker 1954, 1960). In the valley along the lower Illinois River, Port-Orford-cedar is apparently quite rare and present only in moist, sheltered creek bottoms (Emmingham 1973). In the upper Illinois watershed, it is important in a variety of situations. Atzet (1979) recognizes a ***Chamaecyparis lawsoniana*** group of four communities, which includes 42 plots of the 250 ha surveyed (table 24). The first three communities constitute the ***Chamaecyparis lawsoniana*** zone where Port-Orford-cedar is reproducing effectively; in the fourth, white fir will at least share dominance at climax. Douglas-fir and white fir are significant; western white pine is scattered; Brewer spruce ***(Picea breweriana*** Wats.) is most common within the ***Chamaecyparis*** zone. Port-Orford-cedar forest grows primarily on protected, moist, midslope positions on northerly aspects on all parent materials (fig. 9), although it is relatively more common on ultramafics than are other forest types. Port-Orford-cedar often occurs in Atzet's (1979) ***Pinus jeffreyi*** zone on ultramafic rocks, with ponderosa pine ***(Pinus ponderosa*** Dougl. ex Laws.) and incense-cedar ***(Libocedrus decurrens*** Torr.). It is rare in other moist zones Atzet recognized and is absent from the xeric ones (table 24, fig. 9).

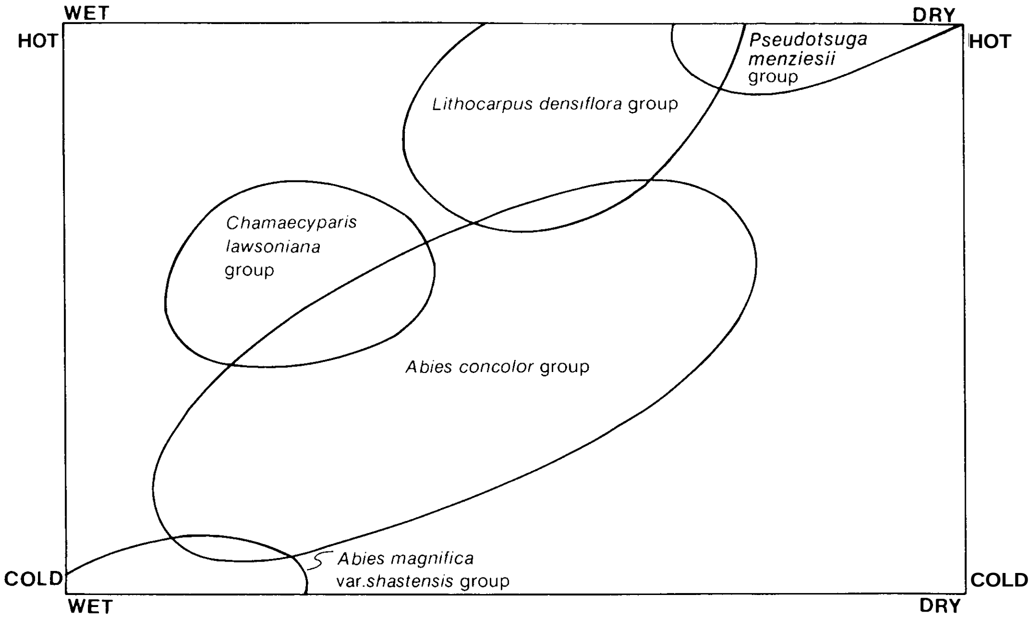

Figure 9.—Relative environmental position of the groups of forest communities, upper Illinois River drainage, Siskiyou National Forest (from Atzet 1979, fig. 67).

Whittaker's studies (1954, 1960) illustrate the gradient nature of the vegetation. His work emphasizes low elevations more than Atzet's does but is limited to ultramafics, gabbro, and diorite, the parent materials where Port-Orford-cedar is more important. The species is usually limited on all parent materials to the most mesic habitats, such as ravines with active streams and, sometimes, sheltered or northerly slopes; the habitat expands at high elevations and is widest on diorite (figs. 10 and 11, table 25). In all stands where reproduction occurs, Port-Orford-cedar is the most commonly reproducing conifer. It is most important above 760 m on diorite (table 26). On diorite the *Chamaecyparis-Pseudotsuga* forest has few sclerophylls and many deciduous trees. On gabbro, Port-Orford-cedar is less common and forests are more open; sugar pine, ponderosa pine, and incense-cedar are significant (fig. 12). On ultramafics, Port-Orford-cedar and western white pine share dominance (fig. 12); the cedar is dominant among the larger stems. Forests on ultramafics have the two-phased understory described for Hawk's (1977) mixed pine community.

Discussion.—Inconsistencies exist among the various descriptions of Port-Orford-cedar forest. Some may reflect differences in sampling strategy used by investigators. Hawk (1977) chose the best developed cedar forests, which are also the best developed of all forests throughout most of the range. Most other investigators sampled to represent the whole landscape. It is no wonder that Hawk's basal area values (see table 19) exceed those of Atzet (see table 24) for similar forest types.

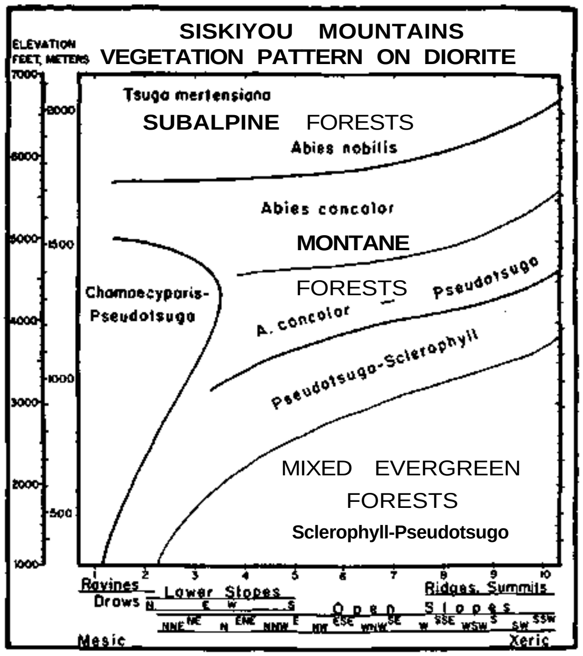

Figure 10.—Mosaic chart of vegetation on quartz diorite, central Siskiyou Mountains, OR. *Abies nobilis = A. magnifica* var. *shastensis or A. procera.* Numbers along the x-axis represent a gradient of wet (1) to dry (10) sites, as defined by topographic features listed below the figure (from Whittaker 1960, fig. 11, used courtesy of the Ecological Society of America, copyright © 1960).

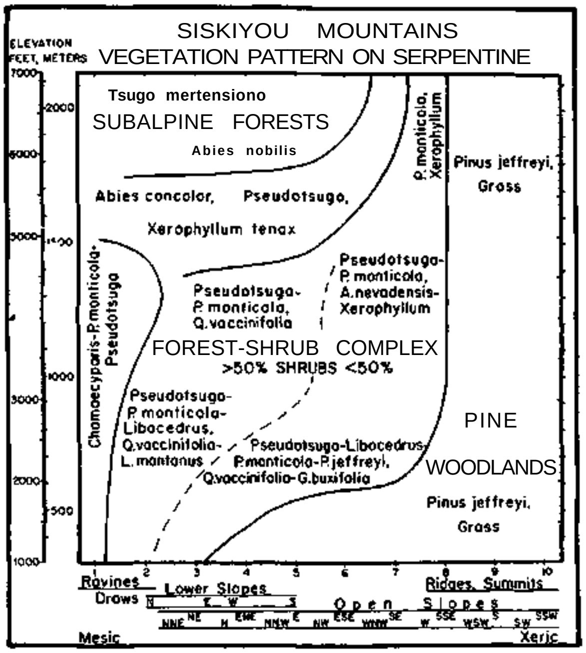

Figure 11.—Mosaic chart of vegetation on peridotite and serpentine, central Siskiyou Mountains, OR (L. *montanus = Lithocarpus densiflora* var. *echinoides; Libocedrus = Calocedrus).* Numbers along the x-axis represent a gradient of wet (1) to dry (10) sites, as defined by topographic features listed below the figure (from Whittaker 1960, fig. 12, used courtesy of the Ecological Society of America, copyright © 1960).

Table 25—Occurrence of Port-Orford-cedar, by position, on the moisture gradient on three intrusive rocks at low elevations (610-915 m), Illinois River Valley, OR

Rock type	Step on moisture gradient 1/	Tree density		Port-Orford-cedar		
		All	Large only 2/	All	Large only 2/	Seedling frequency 3/
		- - number/ha - -		- - - percent - - -		
Diorite	1	810	136	25	40	2
	2	776	160	9	9	2
Olivine gabbro	1	850	34	20	35	4
	2	1496	38	1	21	--
Serpentine	1	838	272	37	72	6
	2	454	136	2	6	--
	4	542	88	1	2	--
	5	518	112	3	9	--

-- = absent.

1/ Whittaker recognized 10 steps of a complex, mositure-related gradient: 1 = most mesic, 10 = most xeric.

2/ Data are for trees > 37 cm d.b.h., except > 25 cm on serpentine.

3/ Number of 1-m^2 plots with cedar seedlings per thousand plots sampled.

Source: Whittaker 1960.

Table 26—Occurrence of Port-Orford-cedar on diorite at four elevations, Illinois River Valley, OR

Elevation	All trees > 1 cm	Conifers > 37 cm	Port-Orford-cedar 1/ Trees > 1 cm	Port-Orford-cedar 1/ Conifers > 37 cm	Port-Orford-cedar seedling frequency 2/
meters	- - number/ha - -		- - - percent - - -		
460-760	1669	87	1	10	2
760-1070	1031	140	10	24	13
1070-1370	518	183	17	17	7
1370-1680	523	199	14	12	9

1/ Importance of cedar as a percent of all trees (>1 cm) and as a percent of large conifers (> 37 cm) in plots within each elevational segment.

2/ Number of 1-m^2 plots with cedar seedlings per thousand plots sampled.

Source: Whittaker 1960.

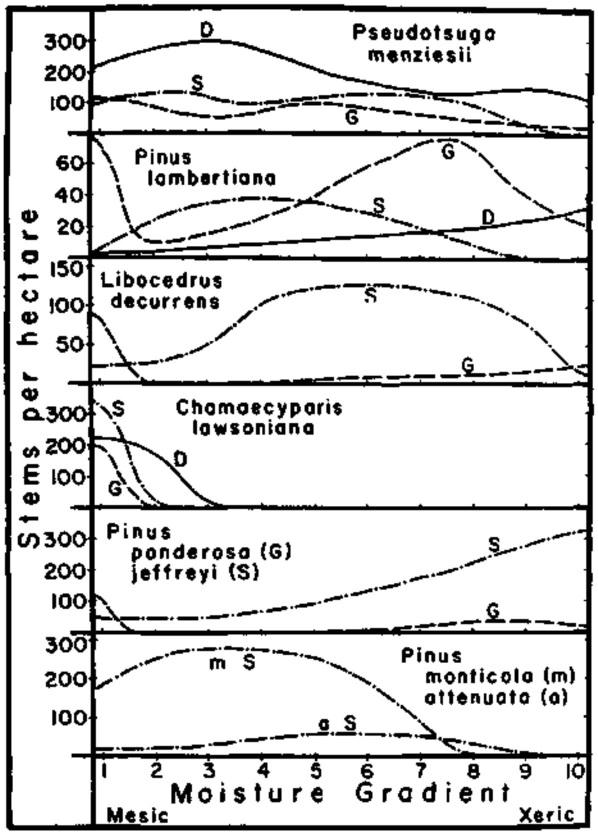

Figure 12.—Population distributions of conifers in relation to topographic moisture gradients at low elevations on diorite (D), gabbro (G), and serpentine (S) soils. Populations on diorite are represented by continuous lines; those on gabbro by broken lines; and those on serpentine by dot-and-dash lines (from Whittaker 1960, fig. 20, used courtesy of the Ecological Society of America, copyright © 1960).

A major inconsistency is between Whittaker's (1960, p. 316) emphasis on Port-Orford-cedar being a "parent material ubiquist" and Hawk's conclusion that it is limited primarily to ultramafic substrates at low elevations in the south. Several factors, besides differences in the precise areas sampled, seem to contribute to the different conclusions. Whittaker sampled only intrusive parent materials, on which the tree is apparently most important. At low elevations on diorite, the tree was considerably less common than at high elevations (table 26); furthermore, Hawk's sampling 25 years later required undisturbed, well-developed cedar forests, which remained on diorite only at high elevations. Hawk's sampling was also much less intensive in a given area than was that of most other investigators, and he did not sample the major low-elevation populations on sedimentary rocks in California. Our survey of the forest descriptions led us to conclude that the tree may occur on most rock types. At low elevations, Port-Orford-cedar forest occurs most consistently and is most common on (or near) ultramafic rocks. It grows well, however, on sedimentary rocks in the Coquille drainage and the lower Klamath drainage—in climates where western hemlock can grow.

Table 27—Relative importance of Port-Orford-cedar in 16-ha units, coastal old-growth forest, Coos County, OR

Total live timber volume per 16-ha unit	Port-Orford-cedar volume
Cubic meters per hectare	Percent of total
< 350 1/	38
350-700	11
700-1050	10
1050-1400	2
> 1400	1

1/ Recent burns.

Source: 1909-12 cruises of Beaver Hill Unit, Coos County Forest; provided by Ted Ellingsen, Coos County Forester.

Tree Composition of the Forest

Some data on tree composition are available from vegetation surveys (see tables 18, 20, 23, 24, 25, 26). As discussed above, values from these small, subjectively chosen plots may be much higher than are regional averages. Large-scale forest surveys of virgin Port-Orford-cedar forests exist for the Coos County Forest,[6] for the defunct Port-Orford-Cedar Experimental Forest in the drainage of the south fork of the Coquille River,[7] and the Bluff Creek project in the Six Rivers National Forest, 11-18 km west of Orleans, CA.[8]

Cruise data from 1909-1912 were available for about 220, 16.2-ha lots of old-growth forest in the Beaver Hill unit of the Coos County Forest. This area is about 15 km south of Marshfield (now Coos Bay). The average volume for all species was 1063 m^3/ha, with the following composition: Sitka spruce, 57 percent; Douglas-fir, 34 percent; western hemlock, 5 percent; Port-Orford-cedar, 4 percent (a mean of 42.5 m^3/ha); and a trace of western redcedar. The distribution of Port-Orford-cedar was spotty: it was absent from 43 percent of the units surveyed and was most important on recent burns (probably as survivors or dead merchantable timber) and in the less productive forests (table 27). Cedar was often most important on level, poorly drained topography? The greatest estimated volume of cedar was about 530 m^3/ha.

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[6] Data on file, Coos County Forest, Coos County Courthouse, Coquille, Oregon.

[7] Data on file, Powers Ranger District, Powers, Oregon.

[8] Data on file, Orleans Ranger District, Orleans, California.

[9] Personal communication, 1981, Ted Ellingsen, Coos County Forest, Coquille, Oregon.

Table 28—Average volumes of Port-Qrford-cedar in old-growth forest in two areas, and maximal volumes for a section and for the smallest sampling unit reported

		Volume of Port-Orford-cedar		
Region and unit	Size of area	Live	Dead	Total live volume
	ha	- - m³/ha - -		percent
Orleans District, CA (1940):				
Blue Lake	1/ 2979	2/ 24.3	1.7	--
Cappell Creek	1/ 1943	2/ 18.6	1.3	--
Highest section	1/ 253	2/ 47.1	5.6	--
Highest one-quarter section	1/ 65	2/ 96.0	11.3	--
Port-Orford-Cedar Experimental Forest, OR (1934-38):				
Experimental Forest	3752	86.0	9.3	26
Research Natural Area	459	117.0	6.2	20
Highest section	338	153.9	25.0	27
Highest lot	16	301.2	66.1	33

-- - total volumes not given.

1/ Precise areas not given; figures are estimated using the nominal size of a quarter section of 64.8 ha.

2/ Percentage of volume of trees in 36- to 66-cm diameter classes is 21, 26, 28, and 29, respectively. The remainder is larger trees'.

In the Orleans study, volumes of large Port-Orford-cedar and selected other species were determined on two units in 1940 (table 28), and the concentration of Port-Orford-cedar was mapped for one of them. This is illustrated in part in figure 13. No information is available about the intensity of the cruise or the log rule employed. Several sections appear to be of nonstandard size which reduces the accuracy of the estimates.

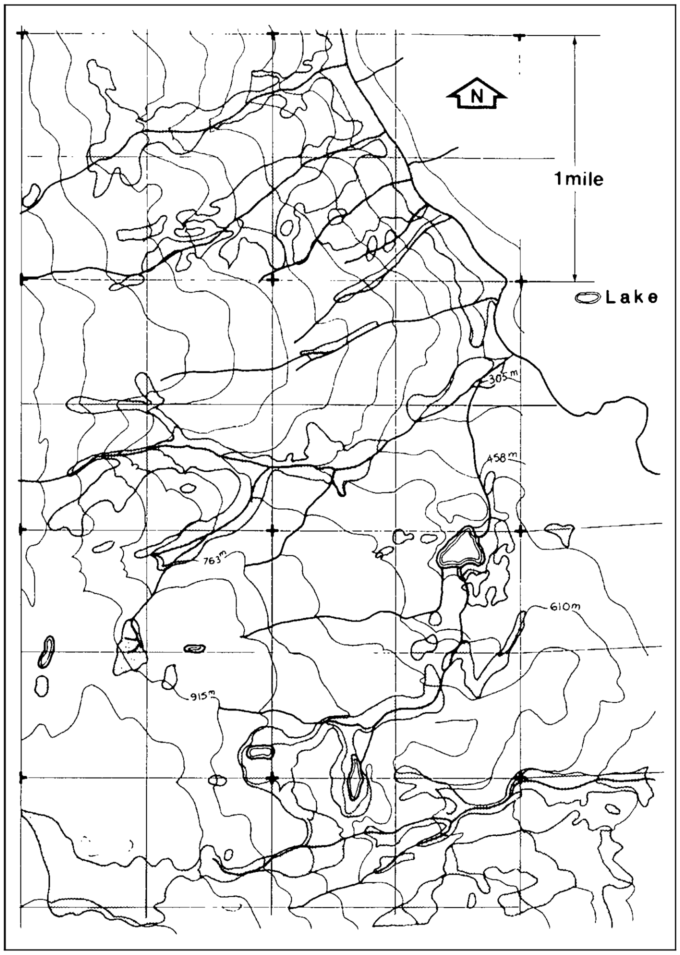

Figure 13.—Area southwest of **Bluff** Creek near Orleans, CA, showing the distribution of Port-Orford-cedar, which is important in the stippled area, in relation to topography. Light lines are contours, interval 250 feet (76.3 meters); heavy lines indicate streams. (Adapted from an unpublished map on file at the Orleans Ranger District, Orleans, CA.)

Volumes of timber in the Port-Orford-Cedar Experimental Forest (in the Coquille River drainage of Oregon) (table 28) greatly exceeded those in the Orleans district and the mean (but not maximum) volume in Coos County Forest. Volume of sound dead trees was significant in both areas. In the Experimental Forest, several forest types were recognized (table 29). Types varied in volume and composition. Port-Orford-cedar exceeded 40 percent of the volume over much of the area (fig. 14); however, Douglas-fir dominated most types. Other trees were usually insignificant, except for pines (table 30) on some ultramafic rocks. Tree density data reemphasize the dominance of Douglas-fir and Port-Orford-cedar (table 31), but their relative importance changed with the type of parent material. Douglas-fir averaged 463 m^3/ha on sedimentary rock and only 46 m^3/ha on ultramafic rock; corresponding volumes of Port-Orford-cedar were 175 and 107 m^3/ha.

Table 29—Definition of forest types recognized for the Port-Orford-Cedar Experimental Forest, 1935-37

Type 1/	Volume of Port-Orford-cedar	Age	D.b.h. of dominant Douglas-fir	Age of Douglas-fir	Volume of sugar pine or western white pine
	Percent	Years	Centimeters		Percent
PC-A	> 40	> 150	--	--	--
PC-B	> 40	75-150	--	--	--
PC-D	> 40	< 75	--	--	--
PC-DA	20-40	--	> 102	Old growth	--
PC-DB	20-40	--	56-102	Old growth	--
DA	< 5	--	> 102	Old growth	--
DA-PC	5-19	--	> 102	Old growth	--
DB	< 5	--	56-102	Old growth	--
DB-PC	5-19	--	56-102	Old growth	--
DC	< 5	--	56-102	Second growth	--
DC-PC	5-19	--	56-102	Second growth	--
DD	< 5	--	15- 56	Second growth	--
DE	< 5	--	< 15	Second growth	--
P-PC-D (mature)	--	--	--	--	> 20
P-PC-D (immature)	--	--	--	--	> 20

-- - not applicable.

1/ PC = Port-Orford-cedar; D = Douglas-fir; P = pine. Last letter in series shows age with A being oldest and E the youngest.

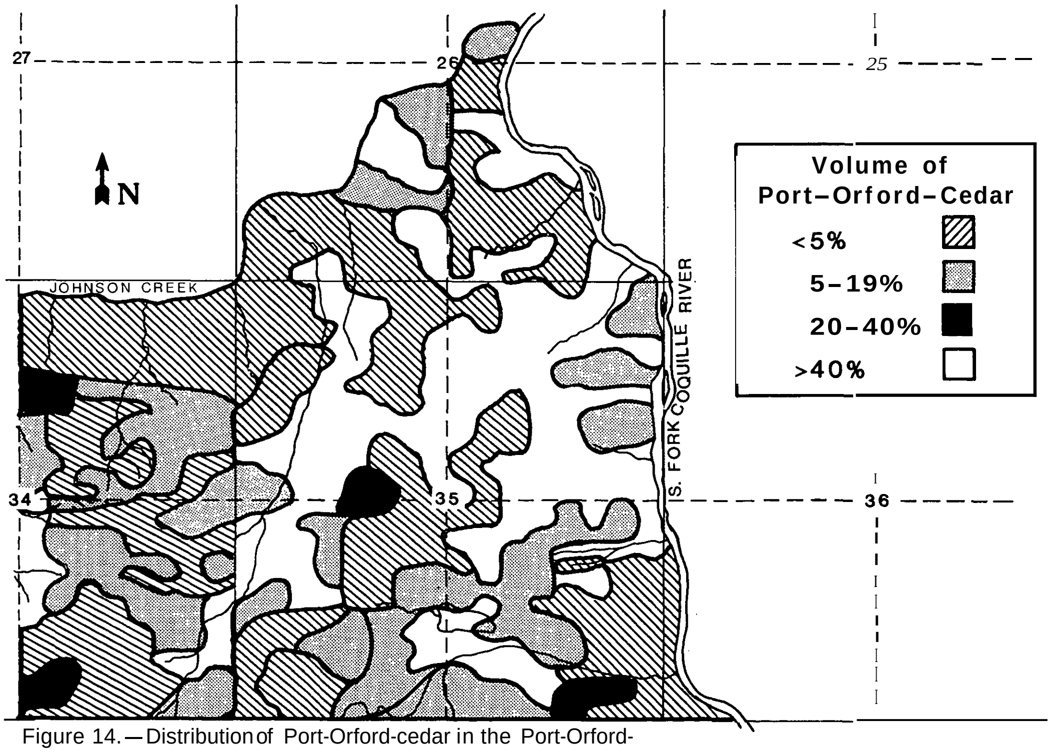

Figure 14.—Distribution of Port-Orford-cedar in the Port-Orford-cedar Research Natural Area, Coos County, OR, shown as a percentage of the total timber volume in 1935-38. Estimates based on a forest type map (types defined in table 29); additional information is in tables 28 and 30. Each large square with the number in the center is a 2.59 km² section. (From an unpublished map section on file at the Powers Ranger District, Powers, OR.)

Table 30—Percentage of board foot volume, by species, in the Port-Orford-Cedar Research Natural Area and other portions of the Port-Orford-Cedar Experimental Forest[1/]

Forest type		Total volume 2/	Volume per species Port-Orford-cedar Live	 Port-Orford-cedar Dead	Douglas-fir	Western hemlock	Western redcedar	Incense cedar	Sugar pine	Western white pine	Grand fir	Deciduous hardwoods	Evergreen hardwoods
	percent	m³/ha	percent										
RESEARCH NATURAL AREA (459 ha)													
PC-A	27	568	54	2	37	3	--	--	--	--	3	1	--
PC-B	1	143	59	14	24	--	--	--	2	--	--	--	1
PC-DA	2	728	26	--	65	2	2	--	--	--	4	--	--
DA	34	608	2	--	87	3	1	--	--	--	5	1	1
DA-PC	21	841	13	1	81	2	1	--	--	--	1	--	1
DB	9	271	2	1	96	--	--	--	--	--	--	--	1
DB-PC	6	279	9	2	87	1	--	--	--	--	--	--	2
REMAINDER OF EXPERIMENTAL FOREST (3293 ha)													
PC-A	43	255	55	6	29	4	--	--	2	3	--	--	--
PC-DA	6	646	26	2	68	1	--	--	1	--	1	--	--
PC-DB	2	306	25	1	62	6	--	--	6	--	--	--	--
DA	7	604	2	1	93	1	--	--	1	--	1	--	--
DA-PC	4	773	14	2	83	1	--	--	1	--	--	--	--
DB	13	353	3	1	89	1	--	--	5	--	1	--	--
DB-PC	1	484	16	2	81	1	--	--	2	--	--	--	--
DD	2	82	3	49	28	--	--	--	--	1	13	2	5
P-PC-D (mature)	12	157	10	1	35	2	--	1	48	4	--	--	1
P-PC-D (immature)	4	25	33	10	21	--	--	--	9	26	--	--	--

-- = absent.

1/ Types with < 1 percent area are excluded; species are listed only where they comprise > 0.5 percent of volume.

2/ Assuming m^3/ha = 71.46 bd. ft./acre (Munns and others 1949).

Source: Unpublished data from a 10-20 percent cruise, 1935-37, on file at Powers Ranger District, Siskiyou National Forest, Powers, OR.

Table 31—Size structure of conifer species on soils derived from sedimentary rocks on 664 ha, Port-Orford-Cedar Experimental Forest[1]

(In trees per hectare)

	Diameter				
Conifers	15-29 cm	30-55 cm	56-105 cm	> 105 cm	Dead
Total area:					
Port-Orford-cedar	4.3	[2] 9.6(37)	[2] 14.8(36)	[2] 5.2(39)	2.3
Douglas-fir	--	12.8	24.3	8.1	--
Western hemlock	--	2.3	.5	0	--
Western redcedar	--	.1	.1	0	--
Sugar pine	--	.1	.2	0	--
Grand fir	--	1.1	1.3	0	1
16-ha lot:					
Port-Orford-cedar (maximum density)	13.6	22.8	26.6	13.6	7.6

-- - absent.

[1] Major forest types, as defined in table 29, were PC-A (23 percent), PC-DA 718 percent), DB (14 percent), and DA (10 percent).

[2] The percentage is shown in parentheses.

Source: Unpublished data from a 10-percent cruise in 1935 of Sec. 7, 18, and 19, T. 33 S., R. 11 W., on file at Powers Ranger District, Siskiyou National Forest, Powers, OR.

Comparisons among the cruise data sets are difficult. Because foresters change the merchantable diameter limits they use and the rules for judging defect, the older volumes may be only about half those produced by present day workers in the same timber (see footnote 9). To convert from board feet to cubic feet, a factor of 5 board feet per cubic foot was used (Munns and others 1949).

Stand volume data for natural young-growth stands are available only for the ***Picea*** sitchensis zone (table 32).

Table 32—Density, basal area, and volume of natural, young-growth Port-Orford-cedar stands along the Oregon coast

		All species		Port-Orford-cedar				
Location	Stand age	Density	Basal area	Stems	Basal area	Mean diameter	Mean height 1/	Volume
	years	number/ha	m^2/ha	percent		cm	meters	m^3/ha
Coos County Forest	36	3361	68.4	60	60	16	16	244
	40	2817	71.6	48	50	18	16	205
	2/ 65	1107	96.7	86	62	27	24	--
Coos-Curry County line	44	1853	93.7	81	70	24	22	506
	43	1705	79.9	81	64	22	22	445
Port Orford	61	1680	112.5	87	80	28	23	838
	57	1656	125.8	90	92	31	22	966

-- = absent.

1/ Height of tree with mean basal area.

2/ Data from two 375-m^2 plots of Hawk (1977).

Source: Primarily Hayes 1958.

Areas With Protected Port-Orford-Cedar Forests

Natural forests that include Port-Orford-cedar are found in five established and three proposed Research Natural Areas (table 33). Full descriptions of three of the established areas are given by Franklin and others (1972). The two largest Research Natural Areas are only 3 to 4 km apart and have had substantial mortality since about 1968 from root rot, especially in trees below roads and along drainages. Most of the sparse Port-Orford-cedar in the proposed Lemmingsworth Gulch Research Natural Area have already died from root rot.

The largest protected area where Port-Orford-cedar is found is the Kalmiopsis Wilderness Area. This is a 72 788-ha area at about 100-1400 m elevation in the Siskiyou National Forest, OR. Port-Orford-cedar is a minor part of the forest: the cedar can occur in concave sites throughout the area, but grows primarily in open forests on ultramafic rocks. Cedar in small numbers is also protected along with redwood in the Jedediah Smith Redwoods State Park, Del Norte County, CA. Well-developed stands occur in the proposed Siskiyou Mountain Wilderness Area in northwestern Siskiyou County, CA (Siemens 1972).

Stands having a more limited protected status also occur in a few hectares of the Port-Orford-Cedar Management Area, Happy Camp Ranger District, Klamath National Forest, Siskiyou County, CA, and in a larger area near Blue Lake, Orleans Ranger District, Six Rivers National Forest, Humboldt County, CA.

The major, and only explicit, formal protection of cedar stands occurred in 1937 and 1945 in two areas of Coos County. An effort to locate suitable Research Natural Areas in California was made in the late 1970's. Even if all the proposed Research Natural Areas are established, the actual area of cedar forest will be far below the 2000 ha suggested by Dion (1938), and much of it is in areas having a high risk of further depredation or infection by root rot. The forest types most poorly represented are those of major commercial importance; their representation will decline as root rot mortality continues to spread in Coos County.

Table 33—Locations and characteristics of Research Natural Areas that have Port-Orford-cedar forests

Name	County	Area	Elevation	Vegetation zone	Agency 1/
		Hectares	Meters		
Established areas:					
Beatty Creek 2/	Douglas, OR	70	365-610	Mixed evergreen	BLM
Brewer Spruce 3/	Josephine, OR	169	1250-1665	*Abies concolor*	BLM
Coquille River—Falls	Coos, OR	202	305-760	*Tsuga heterophylla*	FS
Port-Orford-cedar	Coos, OR	454	260-760	*Tsuga heterophylla*	FS
Woodcock Bog 2/	Josephine, OR	45	455-825	Mixed evergreen	BLM
Proposed areas:					
Adorni	Humboldt, CA	ca. 243	185-730	Mixed evergreen	FS
Cedar Basin	Siskiyou, CA	ca. 400	1645-2120	*Abies concolor*	FS
Lemmingsworth Gulch 2/	Curry, OR	484	335-830	Mixed evergreen	FS

1/ BLM = Bureau of Land Management; FS = USDA Forest Service.

2/ Port-Orford-cedar is not the major part of the value preserved in these Research Natural Areas. It is not in commercial quantity and is in a position particularly susceptible to infection by the root rot.

3/ Also includes Alaska-cedar.

Chapter 5: Characteristics of the Species

Taxonomy

Port-Orford-cedar is classified as ***Chamaecyparis lawsoniana*** (A. Murr.) Parl., in the tribe Cupresseae (Li 1953), of the family Cupressaceae. Other common names are Lawson Cypress, Oregon-cedar, white cedar, ginger pine, and Port-Orford-white-cedar. The genus ***Chamaecyparis*** includes eight taxa, all found in coastal regions (Florin 1963) with six around the northern rim of the Pacific Ocean. Two species in Japan and two in Taiwan occur in temperate montane forests, similar in some ways to those where Port-Orford-cedar grows (Hawk 1977, Sato 1974). The other North American taxa differ considerably in their ecology: Alaska-cedar occurs in cold-temperate and subalpine forests, whereas Atlantic white-cedar grows in swamp forests along the Atlantic and Gulf Coasts of the United States. (The southern populations of ***C. thyoides*** are sometimes classified as ***C. henryae*** Li). Some authors (for example, Edwards 1983) include ***Cupressus funebris*** of central China in ***Chamaecyparis.***

Port-Orford-cedar is the largest member of its genus, exceeding 60 m in height, 2 m in diameter, and 600 years in age. Its wood is rot resistant, has fine, uniform texture, straight grain, great dimensional stability, and is easily worked. Among the Cupressaceae, the tribe Cupresseae is distinguished by its spherical cones that bear 6-16 pairs of imbricated, thickened, shield-like scales (Li 1953). ***Chamaecyparis*** differs from ***Cupressus,*** the other American genus in the tribe, by its flattened branchlets and by having only 2-5 seeds per cone scale.

Table 34—Differences in foliar and cone characteristics that are used to separate Port-Orford-cedar and Alaska-cedar

Characteristic	Port-Orford-cedar	Alaska-cedar
Leaf length (millimeters)	1.5	3
Marginal vs. facial leaves	Marginal longer	Similar
Leaf glands	Obvious	Not obvious
Twigs	Flattened	Not flattened
Wax on protected leaf surfaces	Conspicuous	Little or none
Cone scale number	7 to 10	4 to 6
Cone scale projection	Present, but not prominent	Prominent

Source: Seven taxonomic manuals designed for use with natural populations.

Port-Orford-cedar occasionally grows with Alaska-cedar, and separating specimens can sometimes be difficult when using commonly cited morphological differences (table 34). Differences in leaf surface wax often disappear during drying of herbarium species. Relative length of facial and marginal leaves, “flatness” of the branchlets, and length of the outer protrusion of the cone scale intergrade between the species? Presence of obvious leaf “glands” (pockets of resin just beneath the surface of facial leaves) on Port-Orford-cedar and its 7-10 cone scales seem more reliable for discriminating between the two cedars. Edwards (1983) provides a list of 20 potential taxonomic characteristics for foliage, seed, and cones that occur in field-grown plants.

Distinguishing Port-Orford-cedar without cones from incense-cedar and western redcedar may also be necessary in natural forests. Foliar differences among the three are usually quite distinct in the sun, but separating Port-Orford-cedar from western redcedar can be difficult in the shade. A useful characteristic in these cases is the distinct zig-zag nature of small western redcedar branches, a feature absent from Port-Orford-cedar.[11] Edwards (1983) provides detailed instructions for separating the three genera. Young seedlings of Port-Orford-cedar can be separated from associated conifers because they have only two cotyledons, each 5-10 mm long and flat in cross section, and they have juvenile needles with both surfaces being glaucous (Franklin 1961). Seedlings of Alaska-cedar continue to produce juvenile foliage long after Port-Orford-cedar seedlings growing under the same conditions have ceased.

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[10] Data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.

[11] Personal communication, 1979, D.K. Imper, USDA Forest Service, Six Rivers National Forest, Eureka, California.

General Characteristics of Cupressaceae

Several characteristics of Port-Orford-cedar are typical for all Cupressaceae but are quite different from its major associates—Pinaceae. Some of the characteristics may be of considerable significance to the ecology. Mature leaves are small, scale-like, and appressed to the branchlet: the branchlets are shed as a unit. Masters (1891) suggests that small branchlets of Cupressaceae function analogously to leaves in Pinaceae. Unlike the Pinaceae, there are no bud scales and no preformation of a primary shoot that can rapidly elongate early in the following season.

As previously noted, the litter is less acidic than that produced by most Pinaceae, and Port-Orford-cedar has much thicker bark than most Cupressaceae, especially at the base of old trees. Bark thicknesses up to 25 cm have been reported (Sargent 1896).

Shoot Development

Port-Orford-cedar develops three distinct types of leaves: cotyledons; similar but pointed primary (juvenile) leaves; and closely appressed, scale-like mature foliage (Daguillon 1899a, 1899b; Franklin 1961; Rouane 1973; Sudworth 1908). Figure 15 illustrates primary leaves and intermediate stages in development. The scale leaves occur in pairs, with alternate pairs oriented at right angles to each other. Facial leaves grow in the flattened portion of the branchlet; folded "lateral" or "marginal" leaves form the edges of the branchlet (fig. 16).

Leaf development and anatomy are described by Al-Sherifi (1952), Daguillon (1899a, 1899b), Edwards (1983), Fitting (1950), Masters (1891, 1896), Napp-Zinn (1966), and Oladele (1982) and stomatal distribution on the leaves by Florin (1931) and Zobel and others (1978). Changes in leaf structure during the progression from cotyledon to the scale leaf include: stomatal distribution changing from one to both faces of the leaves; appearance of a resin canal; increase in hypoderm tissue; greater cutinization of the epidermis; and greater development of the vascular bundle. The cuticle has small, cubical crystals, usually near the upper surface, with more on the abaxial side of the leaf (Al-Sherifi 1952, Oladele 1982).

Some leaf characteristics appear to retard water loss. The small leaves are closely appressed to the twig, and most stomata open into narrow clefts between the leaves. Stomata are more common on the adaxial surface. The guard cells are somewhat sunken. Accessory cells on the epidermis around the stomata have a wall-like protrusion around the outer stomatal chamber, and their surfaces have papillae composed of cutin, as in many other Cupressaceae. These protrusions from the epidermal surface are thought to reduce transpiration by Eurasian species of Cupressus and Thuja (Oppenheimer 1970). A layer of hypodermal fibers is common on the adaxial leaf surface. Transfusion tissue of the leaf, sometimes thought to affect leaf water relations, is simpler and less developed than in some conifers (Al-Sherifi 1952). The small leaf size of Port-Orford-cedar should theoretically be expected in saturated, as well as arid, habitats (Givnish 1978). The flattened branchlet has much higher surface-to-volume ratio, however, than do the round branchlets of Cupressaceae from arid climates. A cuticle thickness of 5 μ is given for leaf surfaces of the "normal" form, but it varies between 4 and 15 μ on four cultivated varieties (Napp-Zinn 1966).

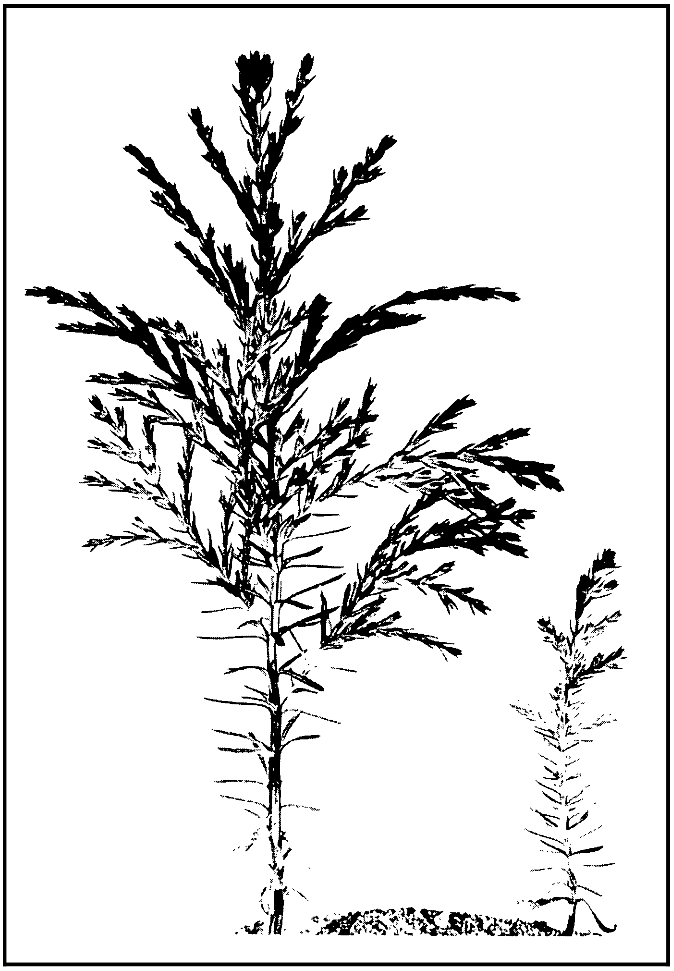

Figure 15.—Seedlings of Port-Orford-cedar at the end of the first growing season in the greenhouse (from Franklin 1961, USFS Photo 498701).

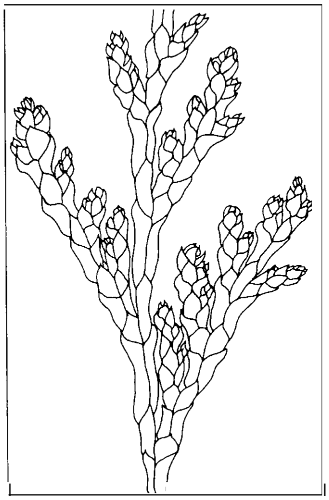

Figure 16.—A branchlet of Port-Orford-cedar, showing the facial and marginal leaves and the pattern of branching (from Rouane 1973, fig. 30, used courtesy Laboratoire Forestier de Toulouse).

Only 16 percent of the surface of scale leaves of nursery-grown seedlings bear stomata, with 56 and 60 stomata per square millimeter on facial and lateral leaves, respectively. The length of a stomatal pore is about 25 μ (Camus [1914] cites 35-40 μ). Seedlings from sources in Coos County have more leaf surface bearing stomata and more stomata than seedlings from high-elevation Josephine County (Zobel and others 1978).

Leaf characteristics may vary even within a mature individual; for example, leaf characteristics change with branch order (Edwards 1983), and on rapidly growing shoots the distinction between facial and lateral scale leaves may be reduced or even disappear (Rouane 1973). Variability in foliage or branching characteristics, especially common with this species, has resulted in many useful horticultural varieties.

Branching occurs in the axils of lateral leaves only (see fig. 16). The pattern (Masters 1891, Rouane 1973) is relatively regular and leads to the frond-like character of Port-Orford-cedar foliage. Long shoots have longer internodes and fewer branches than do short shoots, but the two types are morphologically similar (Al-Sherifi 1952). Young seedlings have a branching interval of 1.4 cm and an upward angle and narrower crown than most species in the genus (Liu and others 1975). Treatment with gibberellic acid reduces branching but increases height growth (Bonnet-Masimbert 1971). The primary vascularization of the small branches is described by Lemoine-Sebastian (1971).

Development of the trunk of Port-Orford-cedar has been described only in a brief series of pictures (Hejnowicz 1967). Whether or not development is from a single meristem, as in most conifers, is not clear; "leader replacement" possibly occurs, as in some species of hemlock (Hibbs 1981).

The trunk often forks in both native and planted forests. In the native range this is not considered to be a significant problem, but in British plantations (planted at 2.4-m spacing) over half the trees forked below breast height (Macdonald and others 1957). Planting trees closer together reduced low forking by half. In Germany, forking was more common on drier soils (Schwappach 1911).

Because Port-Orford-cedar cultivars do not produce new branches from old wood, they have little capacity to recover from severe damage to the crown, such as deep killing by frost or excessive pruning (Welch 1966).

Root System

The only detailed description of the root system of Port-Orford-cedar is for a dense, 50-year-old stand on a clay-loam soil in coastal Coos County (Gordon 1974, Gordon and Roth 1976). This stand had a very dense network of fibrous, absorbing roots at the surface that resulted from "humus strivers" (roots with unlignified tips that grow up into the surface soil and duff). Humus strivers are produced uniformly along the length of the major horizontal system of surface roots. The number of major surface roots declined linearly away from the trunk, with 20 percent reaching 4 m. Beyond 4 m there was a slower decrease in root frequency, but only 0.6 percent of major roots extended beyond 6.7 m. Port-Orford-cedar has no tap root, but produces vertical sinkers from the horizontal system. Root systems of adjacent trees intermingle freely, with some overlap likely in trees closer than 12 m. Root grafting between trees was common in the main horizontal surface root system, averaging 1.5 grafts per tree; the average graft was 34 cm deep between roots 3.8 cm in diameter. The chance of grafting decreased in a linear manner as horizontal distance between trees increased (becoming very small beyond 6 m) and with vertical distance on the slope. Graft complexes including several trees sometimes joined trees up to 12 m apart, however. Some root systems in a dense, windthrown, 39-year-old plantation north of the range had a surprisingly narrow extent, with a small root diameter where the roots had broken and almost no grafting.

In hydroponic culture, Port-Orford-cedar had a top-to-root dry weight ratio of 2.2 in full light, which was among the highest of eight conifers tested, and 3.0 in 10 percent of full light. This 1.3-fold increase occurred for three other species from the Pacific Northwest coast (including redwood and Douglas-fir); this increase contrasted to the twofold increase in conifers such as Jeffrey pine and incense-cedar, native to more southern areas (Baker 1945).

Root elongation increases at longer photoperiods and affects the tree's susceptibility to *Phytophthora cinnamomi* (Foster and others 1976). Root hairs do not form on Port-Orford-cedar in soil (Jones 1967); however, deviate root tip cells may resemble root hairs. Lateral roots of seedlings grow downward, in contrast to some conifers (Masters 1891). Information on the root apical meristem can be found in Pillai (1964).

Chemistry

The chemistry of Port-Orford-cedar has not been described in much detail, but some aspects are of practical importance. The highly aromatic wood contains substances causing diuresis; sawmills cutting the cedar reportedly had to cut other species intermittently with the cedar to maintain the health of their workers (Sargent 1896).

The oil content of cedar apparently increases the wood's resistance to decay and termites (Carter and Smythe 1974) and is said to have insecticidal properties (Schenck 1912). The heartwood contains fewer compounds than do other Cupressaceae (Erdtman and Norin 1966), although it seems to have been less completely studied. Specifically, (–)-b-bisabolene is the only sesquiterpene hydrocarbon identified; it contains cadinol, a cadinene; and the leaves produce the lignan deoxypodophyllotoxin. No tropolones have been identified from Port-Orford-cedar heartwood, although heartwood has a positive general test for their presence; Port-Orford-cedar lacks the nootkatin found in Alaska-cedar, and the thujaplicins that occur in incense-cedar and western redcedar (Zavarin and Anderson 1956). Pollen of Port-Orford-cedar, along with that of other Cupressaceae, is immunogenic in humans and may be allergenic (Yoo and others 1974). Seeds contain a substance that regulates insect growth (Jacobsen and others 1975). Tannins and mucilage occur in the pith and leaf mesophyll layer (Al-Sherifi 1952, Erspamer 1953).

Genetics and Variability

There is little information about genetics or natural patterns of variability of Port-Orford-cedar. In cultivation, however, it has produced a wider variety of stable horticultural forms than has any other conifer (Bean 1950) (also see next section).

The number of chromosomes in Port-Orford-cedar is n = 11 (Munz and Keck 1959, citing Sax and Sax 1933), as it is for others in its family (Maeta and Yamamoto 1981, Sporne 1965).

Some recent studies in a common garden have measured variabililty among seedlings taken from sources in contrasting environments. Plocher (1977) found differences in growth and foliar nutrient concentrations for seedlings transplanted from different soil types in Coos County (see Chapter 6). Three studiss in a Taiwanese nursery compared seedlings of coastal Coos County sources with those from high elevations in Josephine County. The coastal provenance had a higher percentage of the leaf surface with stomata and a (nonsignificantly) higher stomatal frequency (Zobel and others 1978); higher Ca and zinc (Zn) concentrations in foliage (Zobel and Liu 1979); but no consistent differences in leaf resistance to transpiration (Zobel and Liu 1980). Growth of cuttings from northern coastal trees was somewhat more than for cuttings from high elevations and from a source along the Sacramento River the first year, but not during the second (see table 51 and Zobel [1983]). Liu and others (1975), who used three seed lots of uncertain origin (including one cultivar), found some differences in early seedling morphology among sources. Compared to most Pinaceae, Port-Orford-cedar displays little genetic variation in timing of shoot elongation (Zobel 1983).

No provenance plantations have apparently been made (Macdonald and others 1957), although Boudru (1945) speculates that useful variability exists within the species. It may be that the potential of cedar in exotic plantations has been limited by the few original sources of seed used. The earliest seed collections were made along the Sacramento River, and because planted trees produced ample seed, seed was rarely imported into Europe after the potential of Port-Orford-cedar as a timber tree was recognized.

A few selections of “plus trees” and a few hectares of plantations from them have been made in Great Britain (Macdonald and others 1957).

Cultivated Varieties

Port-Orford-cedar—usually referred to as Lawson cypress in cultivation—has produced a tremendous number of variants in size, branching and foliar habit, and in foliar color. This variety of forms has led to its status as one of the most popular and useful of horticultural conifers (Bean 1950, Dallimore and Jackson 1966, Harrison 1975). At least 220 cultivars have been developed (Rouane 1973), and 132 were still being used in 1965 (den Ouden and Boom 1965); however, only 50 or so are available for general cultivation (Harrison 1975). Most cultivars originated in Great Britain or The Netherlands, even most or all of the dozen or more formerly grown in Oregon (the most important being ‘Allumii’) (den Ouden and Boom 1965, Torgeson and others 1954). None are reported as being collected from natural populations and only 2 of the 205 listed by den Ouden and Boom (1965) originated in the United States. One shrubby form (originally Cupressus *attenuata* Gordon) was collected (Gordon 1875) but seems never to have been cultivated. At least one cultivar originated from the first seeds collected in California, which were planted in

Scotland in 1855. At least 27 forms were commercially available by 1875, some of which were developed in Europe (Gordon 1875). Introduction of new forms peaked in the 1890's and 1930's (den Ouden and Boom 1965, Krussman 1960), but new cultivars continue to be developed in Europe and in New Zealand and Australia (Harrison 1975, de Beer 1973). Some cultivars have remained popular for over a century. Of the 27 cultivars known to be available in 1875, 9 are among the 58 listed by Harrison (1975).

Most cultivars, especially the dwarf forms (Welch 1966), originated as seedlings, although rooting of "sports" on other plants has resulted in several new forms (seven listed by den Ouden and Boom [1965]).

Cultivars can be classified into several types. Krussman (1960) cites 67 with upright habit (34 with blue-green and silvery foliage, 22 yellow, 7 green, and 4 variegated); 15 as compact, broadly conical dwarf forms (9 blue-green, 4 green, 1 yellow-green, 1 variegated); 13 as dwarf and broadly hemispherical without a leader (6 blue-green and silvery, 3 green, 3 yellow, 1 variegated); 13 with drooping habit; 8 "curled"; 6 filiform; 4 with transition-form foliage; 3 prostrate; 2 short-stemmed; and 1 with juvenile-form foliage. A cultivar grown from seed and patented in 1973 (de Beer 1973) is distinctive for its combination of blue-gray color; winter hardiness to –30 °C; compact, conical shape; needlelike, decussate leaves 3-6 mm long; and upright, dense branching.

Dwarfism can be extreme: One 1.2-m tall specimen of 'nana' is over 70 years old (Bean 1950). At least two forms of dwarfism occur: in 'minima' the trunk is absent or very small and the plant has several more or less equal, vertical main branches; in contrast, 'nana' always has a well-defined trunk and more horizontal branches. Growth rate can be controlled somewhat by the soil type. Most dwarf forms produce few or no seeds (Welch 1966).

Cultivars vary in resistance to cold (Day and Peace 1946, Duffield 1956, Harrison 1975, Welch 1966). Harrison (1975) cites 35 forms that are hardy at –24 to –30 °C, 19 forms at –18 to –24 °C, and 2 at –13 to –18 °C. In general, the dwarf forms are less resistant to cold than are taller forms, and those with variegated or yellow foliage less resistant than green or bluish cultivars (Harrison 1975, Welch 1966). Cultivars also vary in susceptibility to *Phytophthora cinnamomi* (Torgeson 1953, Yates 1972), and in rooting capacity (see Chapter 6). Some of the color variation is attributable to differences in shading and soil (Welch 1966). The species can be easily shaped by pruning (Lamb 1938); however, pruning too deeply is detrimental as the species does not produce new branches from old wood (Welch 1966).

Many of the important characteristics of the ornamentals can be seen in natural populations. Perhaps the most obvious difference among native trees is in their color. Trees with bluish foliage occur throughout the range and variegated trees have been seen in Coos County. Differences in foliage form and branch angle (that is, drooping secondary branches) are also present. One difference among some cultivars (Welch 1966) is the relative length of the leading shoot of a branch and its laterals; similar differences occur among native trees. Shrub forms of the 'minima' type occur in open areas, most often on ultramafic soils; some natural shrubby plants have a much more open, sprawling nature.

Hybridization

A morphological analysis of trees from two sympatric natural populations of Port-Orford-cedar and Alaska-cedar[12] revealed only one tree in northwestern Siskiyou County with definitely intermediate characteristics. Its leaves had resin pockets and waxy portions as Port-Orford-cedar does, but the twigs were much less flattened; its ratio of marginal to facial leaf length was intermediate; its cones had longer protrusions from the scales than most; and it had cones with 5, 6, 7, and 9 scales; many of the cones with 7 scales included scales that were incompletely separated.

A presumed hybrid (the cultivar 'nidiformis') of Port-Orford-cedar and Alaska-cedar was discovered at a nursery in Italy. The leaf structure of this shrubby cultivar is intermediate between the two species (Dallimore and Jackson 1966, Nicholson 1889), but den Ouden and Boom (1965) are skeptical of its hybrid origin.

Artificial hybrids with Atlantic white-cedar and the two Japanese species have been made (Maeta and Yamamoto 1981; Yamamoto 1981a, 1981b). Indices of the productivity of filled seed were calculated for the hybrids; 100 was the number assigned to crosses within the same species. Index values are given for Port-Orford-cedar as the female parent (the first number) and as male parent (the second number): 1.9/5.5 with Atlantic white-cedar, 29.4/(cross not made) with ***C. pisifera*** ([Sieb. & Zucc.] Endl.) (Sarawa cypress), and 18.1/0.2 with ***C. obtusa*** ([Sieb. & Zucc.] Endl.) (hinoki). However, 85 percent of seedlings from the Sarawa cypress cross lacked chlorophyll, and seeds of Atlantic white-cedar crosses were inviable. Germination and survival of hybrids with hinoki were better than for the pure Port-Orford-cedar tested, partially because of the hybrid's greater resistance to damping off.

Because other species of ***Chamaecyparis*** are immune or only slightly susceptible to ***Phytophthora lateralis*** Tuck. & J.A. Milb., hybridization may provide some potential for developing trees similar to Port-Orford-cedar that are less threatened by root rot.

Wood Properties

Sapwood of Port-Orford-cedar is white, 2.5-8 cm thick, moist (200 percent), and often difficult to distinguish from the heartwood. It comprises 10-15 percent of a sample of second-growth bolts. Heartwood is creamy white, drier (40 percent moisture), and straight grained, with narrow rays and no resin canals. The narrow late-wood zone is only slightly denser than early wood. This uniform wood is easy to kiln dry and easy to work with, as it has little tendency to splinter when sawed or for the grain to tear when planed. When used for decking, it wears evenly without splintering. It is easily peeled on a veneer lathe. Tolerance of 0.05 mm can be maintained during machining. Knots are relatively small and tight. It is not liable to warp, is easy to glue, and takes a good polish. Along with other cedars and redwood, Port Orford cedar holds all common kinds of paints better than do most other woods. (This summary above is from Henley 1973, Laughnan 1959, Panshin and deZeeuw 1970, Port Orford Cedar Products Company 1929, Sargent 1885 and Stillinger 1953.)

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[12] D.B. Zobel and K.M. Reynolds, unpublished manuscript, on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Wood from Port-Orford-cedar is moderately light in weight. Its specific gravity is 0.40 green and 0.44 oven dry (Panshin and deZeeuw 1970), although various other values have been given: 0.33 (Lavers 1969) to 0.47 (Port Orford Cedar Products Company 1929). Stillinger (1953) found a decrease in specific gravity away from the pith (0.400 to 0.381) and toward the top of the tree (0.406 to 0.345).

The straightness of the grain is emphasized by studies of dye movement: In Port-Orford-cedar and western redcedar, injected dye travels up the tree with little lateral movement and without the spiral path characteristic of many conifers (Vite and Rudinsky 1959).

The wood is stiff, moderately strong and hard, and moderately resistant to shock (Henley 1973). A reevaluation in 1972 of structural properties of Port-Orford-cedar wood produced values (table 35) higher than for western redcedar, sugar pine, and western white pine, which were sampled concurrently.

Strength properties of Port-Orford-cedar grown in New Zealand are similar to Douglas-fir grown there.[13] In sharp contrast, trees grown in Great Britain have wood that is lighter and much weaker than that from cedar grown in the United States, both in absolute terms and relative to western redcedar and other conifers (table 36). Some British authors also note that oiliness of Port-Orford-cedar wood tends to clog tools and the wood is difficult to smooth (Howard 1948), contrary to the information presented above. Wood grown in New Zealand is about as dense as that from the United States (Streets 1962). Port-Orford-cedar has relatively high rolling shear strength (2.24 N/mm^2) (Bendtsen 1976). The elastic parameters for cedar wood have been calculated from other wood properties (Bodig and Goodman 1973).

Strength properties of second-growth trees in the United States are similar to those for old growth (Stillinger 1953). Among second-growth trees, a few properties varied with growth rate (fast growth, ≤ 8 rings per inch; slow growth, >17 rings per inch): shrinkage, the modulus of elasticity, and the modulus of rupture all were lower in fast-growing samples.

Port-Orford-cedar shrank 4.6 percent radially and 6.9 percent tangentially (10.1 percent in volume) during drying to zero moisture (Peck 1957); this was more than for other western Cupressaceae (6.8 to 9.2 percent) but intermediate among other western woods. An earlier estimate of shrinkage from green to oven dry was 5.2 percent radially and 8.1 percent tangentially (Port Orford Cedar Products Company 1929).

Although Henley (1973) cites a “high resistance to the action of acids” for Port-Orford-cedar wood, Ross’ results (1956) indicate an intermediate position relative to 15 other conifer woods (13 western species). The average percentage of wet breaking strength retained after treatment was: 65 percent in 11 acid treatments, with other species varying from 60 to 70 percent (cedar being seventh highest of the 16 woods); 43 percent after exposure to five bases (range 37 to 56) (twelfth); and 89 percent in eight salt solutions (range 80 to 94) (sixth). It was relatively resistant to sodium hypochlorite—fourth most resistant of the species studied.

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[13] Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua, New Zealand.

Table 35—Average specific gravity and mechanical properties of Port-Orford-cedar wood in a green moisture condition and at 12 percent moisture content for 33 randomly selected trees 1/ from throughout the range

Attribute	Moisture content	
	Green	12 percent
Specific gravity	0.39	0.43
Static bending:		
Modulus of rupture (N/mm^2) 2/	3/ 45.5	3/ 87.7
Modulus of elasticity (N/mm^2)	8,945	11,717
Maximum crushing strength parallel to grain (N/mm^2)	21.7	43.1
Maximum shear strength parallel to grain (N/mm^2)	5.8	3/ 9.4
Compression perpendicular to grain stress at proportional limit (N/mm^2)	2.1	3/ 4.9
Hardness (N): 4/		
End	2,147	3/ 4,267
Side	1,698	3/ 2,791

1/ Mean diameter, 48 cm; range of diameters, 26-61 cm.

2/ 1 N/mm^2 = 145.0 pounds of force per square inch.

3/ Values significantly different from values in the earlier literature. All values denoted thus are higher than earlier values except the modulus of elasticity.

4/ Load required to embed an 11.3-millimeter ball to one-half its diameter.

Source: Bendtsen 1972.

Table 36—Strength properties of Port-Orford-cedar and other western conifers[1/]

Species	Specific gravity	Static bending Maximum bending strength 2/	Stiff-ness 3/	Maximum compression strength 4/	Maximum shearing strength 4/	Hardness 5/
		N/mm^2				N 6/
Port-Orford-cedar	7/ 0.37	68	5400	28.7	10.8	2620
Western redcedar	.33	65	7000	35.0	8.5	2000
Douglas-fir	.44	91	10500	48.3	11.6	3420
Grand fir	.32	57	7000	30.1	7.7	1780
Noble fir	.33	63	8100	31.0	9.3	2000
Western hemlock	.38	76	8000	41.3	10.6	2580
Lodgepole pine	.42	79	8100	38.2	12.1	2940
Sitka spruce	.34	67	8100	36.1	8.7	2140

1/ All values are averages for wood from 5 to 54 trees grown in the United Kingdom, with 12-13 percent moisture content.

2/ Modulus of rupture.

3/ Modulus of elasticity.

4/ Parallel to grain.

5/ Resistance to indentation on side grain.

6/ N = 1 newton = 0.225 pounds of force.

7/ 0.33 using green volume.

Port-Orford-cedar wood has a distinctive, pungent, ginger-like odor, caused by a volatile oil. The odor in a Forest Service building that was constructed primarily of cedar is still intense after more than 40 years. Sawdust and mill residue yielded 1.6 percent oil in a commercial distillation (Thurber and Roll 1927) and stump heartwood, about 5 percent (Kritchevsky and Anderson 1955); the oil was analyzed by both authors. This oil may delay drying of paint but seems to prolong the life of the paint (Laughnan 1959). It also may cause skin rash and eye irritation. Prolonged exposure to the odor and fine sawdust affects kidney function (Henley 1973, Sargent 1881, Sudworth 1908), but the effect is not so pronounced as some early authors indicated (Thurber and Roll 1927).

Resistance to decay and to insects is high for Port-Orford-cedar wood (Henley 1973, Port Orford Cedar Products Company 1929). A sound log wrapped in the roots of 2.3-m diameter spruce was reported by Howard (1948). Untreated cedar pilings and posts remained sound after several decades in soil or exposed to tidewater, and cedar wood lasts well in mines, railroad tunnels, culverts, and ships. Trees killed by fire provide good lumber for decades (Peavy 1922). The wood is difficult to treat with preservatives (Macdonald and others 1957); in New Zealand this difficulty, plus only moderate durability of heartwood produced there, has limited the use of locally grown wood in construction (see footnote 13).

Port-Orford-cedar heartwood was more toxic to termites (*Reticulitermes flavipes* [Kollar]) than were 10 other woods, apparently because of its oil content (Carter and Smythe 1974). Termites will, however, attack weathered Port-Orford-cedar wood from which the oil presumably has been lost.

Its wood properties make Port-Orford-cedar a versatile material. They allow it to be used in traditional Japanese construction methods which use no fasteners, and its grain and color resemble hinoki (Chamaecyparis ***obtusa***), the wood traditionally used in Japan: This accounts for its present high value on the export market. Port-Orford-cedar is the second-choice substitute (after the Taiwanese Chamaecyparis) for fulfilling the symbolic and structural functions of hinoki in Japan. Value of exported logs depends on fineness and evenness of the grain, absence of blemishes, and a less yellow color with some preference for more scent. Anything reducing the uniformity of the cut surface depresses the price. Value increases with log size; large logs allow more options for how the wood is cut and for matching color and grain. Wider panels can be cut. The wood properties that control the price of clear Port-Orford-cedar wood vary significantly within the range of the tree. Exports from near Powers, OR, have recently been most desirable, although some variation in preferences is reported among Japanese consumers.

The wood anatomy of Port-Orford-cedar (Bannan 1950, 1952; Greguss 1955; Panshin and deZeeuw 1970; Phillips 1941) varies within a tree and among trees. No single microscopic characteristic can be used to separate Port-Orford-cedar from Alaska-cedar or Atlantic white-cedar. Several details of ray anatomy used together are useful, however, for distinguishing species (Bannan 1952).

The average diameter of early wood tracheids is (radial x tangential, in μ) 33 x 26 in mature stems (Bannan 1952); it varies from 17 x 17 on the lower side of large branches to 41 x 29 in 1- to 3-cm roots. Bannan (1952) found no difference in tracheid diameter among species. In contrast, Panshin and deZeeuw (1970) list an average tracheid diameter of 34-45 μ, larger than Alaska-cedar and Atlantic white-cedar. Tracheid length increases outward from the pith in Chamaecyparis stems (1.3 to 3.2 mm) and branches (1.3 to 1.9 mm); tracheids are longest in the roots (4.4 mm) (Bannan 1950).

Port-Orford-cedar wood fibers from unbleached, unbeaten kraft pulp (Horn 1974), as compared to 11 other western woods, had low wood density (0.367 g/cm^3 of green volume), a short fiber length (2.98 mm), and small cross-sectional area (110 μ^2), but a large length:thickness ratio (1,406). It also has a large number of fibers per gram (23.08 x 10^5) and per cubic centimeter (15.23 x 10^5) of pulp sheet; thin cell walls (2.12 μ); low pulp fiber coarseness (15.0 mg/100 m); and a moderate fibril angle (8.5 degrees). Most characteristics were similar to Alaska-cedar and western redcedar, but quite different from Pinaceae. Port-Orford-cedar produced paper with moderate stretch, high tensile strength, a high burst factor, a low to moderate tear factor, and a high modulus of elasticity (Horn 1974).

Chapter 6: Autecology

The relatively small amount of literature on the autecology of Port-Orford-cedar has been reviewed by Minore (1979). Based on his summary, the species has the following characteristics (as compared to other conifers of the northwestern United States): moderate shade tolerance; fairly low drought tolerance; a moderately long period of shoot growth; a moderately young seed-bearing age; an average date of seed dissemination; a large seed crop size; moderately small seed; an average seed longevity; little stratification requirement for seed germination; and a high susceptibility to browse by rabbits and deer.

Water Relations

Insufficient water appears to be a very important factor limiting distribution of Port-Orford-cedar (Zobel and Hawk 1980). Several observations suggest the importance of water:

1. Port-Orford-cedar is limited to areas with relatively high ratios of precipitation to evaporation (p:e ratio), as noted in Chapter 2. It grows best as an exotic in similarly moist climates in Europe (Boullard 1974, Macdonald and others 1957).

2. Where the p:e ratio is highest, Port-Orford-cedar grows in dense forests on productive soils, with deep water tables on well-drained topography. In areas with a lower p:e ratio, the species is limited to less productive soils with shallow, persistent water tables, and lower density forest in concave topography (Hawk 1977, Sawyer and Thornburgh 1977, Zobel and Hawk 1980).

3. As climate has dried since the Eocene epoch, the range of Port-Orford-cedar has become restricted to an area with a high p:e ratio and equitable temperatures, similar to the climate in the early Tertiary period (Axelrod 1976a).

4. Water potential of Port-Orford-cedar saplings in late summer is rarely low. Average values are seldom below −9 bars before dawn (all trees below −10 bars are in the mixed evergreen zone); these values are less severe than those experienced by most competing conifers. Areas where the species occurs on drier soils are often near the coast where there is a persistent flow of moist air.

5. Local gradients of plant water potential exist at sites occupied by the cedar; local distribution ends where the most extreme predawn water potentials go below −11 bars.

6. Along gradients of water potential, Port-Orford-cedar often drops out without other changes occurring in tree composition of the forest.

Soil moisture availability for Port-Orford-cedar is lowest in some terrace stands in the mixed evergreen zone (Zobel and Hawk 1980). Average predawn water potentials reached −20 and −17 bars at one site and −25, −19, and −17 at the other in 2 and 3 years of sampling, respectively. Some other environmental factor (or factors) must be highly favorable to allow the cedar to survive on these terraces. One possible compensating factor is recurring morning fog in the valleys (Atzet 1979); even so, these stands are a distinct exception to the usual relationship between Port-Orford-cedar and soil moisture.

Inference from the daily course of water potential suggests that Port-Orford-cedar can effectively control transpiration; daily reduction of sapling water potential was usually less, and midday water potential higher, than for Douglas-fir at the same location (Zobel and Hawk 1980).

The only measurements of leaf resistance to transpiration are for scale leaves on 1-year-old nursery seedlings in warm, well-watered conditions in Taiwan (Zobel and Liu 1980). Leaf resistance was low, the minimum for 5 days of measurement averaging 2.6 s/cm and the maximum, 5.2 (the mean was 4.2). Resistance, and its daily variability, were considerably less than for two Taiwanese ***Chamaecyparis.*** Some individual seed lots of Port-Orford-cedar produced seedlings with consistently high or low leaf resistance, but there was no consistent difference between averages of coastal and inland, high-elevation seed sources. Leaf resistance of Port-Orford-cedar was higher in January than in March and increased during the day and as the air dried. Sensitivity of Port-Orford-cedar to dry air was less than that of the Taiwanese species. There was no evidence of a threshold light intensity for stomatal closure. Resistance of Port-Orford-cedar trees in native environments must certainly exceed the resistance measured in Taiwan.

Several aspects of leaf morphology (Al-Sherifi 1952, Florin 1931, Napp-Zinn 1966, Zobel and others 1978), as described in Chapter 5, may affect water loss by Port-Orford-cedar. Even so, Port-Orford-cedar is not considered especially drought tolerant, as suggested by its distribution pattern. It is, however, considered more drought tolerant than western hemlock, Sitka spruce, and Shasta red fir, but less so than incense-cedar; Douglas-fir; grand and white fir; sugar, Jeffrey, and western white pines; and western redcedar (Minore 1979). Drying winds cause damage (Camus 1914). Extended drought may damage Port-Orford-cedar in its natural habitat (Sudworth 1908, Zobel and Hawk 1980) and elsewhere (Streets 1962, Thogo and Dyson 1974). A major drought in the natural range in 1976-77 damaged trees and reduced growth but only in the open forest where soil water potential had previously been drier than in most areas, or where temperatures were very high (Zobel and Hawk 1980). The effect of that drought was alleviated by a wet May.

Drought resistance may vary with the conditions of water supply. ***Chamaecyparis obtusa,*** for example, was more drought resistant than two other Japanese conifers when root penetration was limited, but was the least resistant species when seedlings had unrestricted rooting depth (Satoo 1956). If Port-Orford-cedar behaves similarly, this might help to explain its dominance on the shallow, rocky, and saturated soils it often occupies (Zobel and Hawk 1980).

Phenological traits that concentrate most growth processes in summer may be more consistently important than is susceptibility to drought in restricting Port-Orford-cedar to areas with ample and persistent water supply. Seeds did not germinate until mid-June in the one study in the natural range (Zobel 1980). A poorly protected apical meristem continues to divide, and leaves and internodes enlarge, producing new unhardened foliage later into the summer than do associated Pinaceae (see Vegetative Phenology section). Reproductive buds also develop through the summer (Hashizume 1973).

Port-Orford-cedar often grows in substrates that are saturated much or all of the year, where few other conifers survive. In the wet, ultramafic meadow community (Hawk 1977), it is the only tree in the wetter portions, even growing in and along the small streams. Although the water table fluctuates considerably in some areas in summer, in other cedar stands it is stable (Zobel and Hawk 1980).

Research in France (Levy 1973) indicates that other factors seem to override the effect of water table. Conifers were planted in soil having a high water table but which had been drained with three intensities of ditching, and on 50-cm ridges on the site. Port-Orford-cedar survived better (89 percent) on ridges than in any drainage treatment (60-72 percent) even though the water table was more shallow than in two of the three drainage conditions. Growth was also better on the ridges (after 2 years the height was 39 cm) than in the drained areas (24 to 31 cm). In contrast, survival and growth of Douglas-fir correlated well with water table depth. The authors do not know what factors controlled the behavior of the cedar. In the native range, areas with high water tables supporting Port-Orford-cedar have continuous water movement, not stagnation, as appeared to occur in Levy's (1973) study.

Mycorrhizae, Tissue Nutrient Concentrations, and Growth

As discussed in Chapter 3, Port-Orford-cedar grows naturally on a wide range of substrates, from very productive to very poor, with large differences in chemical properties. Growth rate and size of trees are correlated with these substrate differences, and differences in soil nutrient availability are a likely cause of variation in growth.

Mycorrhizae.—Port-Orford-cedar forms endomycorrhizae with fungi of the genera *Acaulospora, Gigaspora,* ***Sclerocystis,*** and *Glomus.* Most of the fungal symbionts grow on a wide range of hosts and habitats from moist coastal to inland arid climates (Gerdemann and Trappe 1974). Mycorrhizae collected from eight native stands with variable climate and substrate were all similar (Zobel and Hawk 1980). There seem to be no experimental studies of endomycorrhizal effects on growth of cedar; however, ectomycorrhizal fungi may influence growth or become symbiotic in some conditions (Levisohn 1953, 1954).

Tissue nutrient concentrations.—Nutrients are translocated to the leaves in the xylem sap. In the only study on composition of xylem sap, Port-Orford-cedar sap had a lower content of nitrogen than most conifers studied. No nitrate was found; most of the nitrogen was present in citrulline and glutamic acid, with smaller amounts of seven other amino acids. Citrulline was more important in Port-Orford-cedar than in the other gymnosperms studied (Bollard 1956, 1957).

The nutrient concentrations in foliage of Port-Orford-cedar vary considerably with the conditions of growth (tables 37 through 42). Native saplings showed significant differences in all macronutrients, iron (Fe), and boron (B) that are related to type of parent material (Zobel and Hawk 1980) (tables 37 and 38). On ultramafic substrates, N, P, and K were low, Mg was high, and the Ca:Mg ratio was low. Igneous rocks that were not ultramafic supported trees with high Ca and B and low Fe. Ca:Mg ratios were highest on other igneous rocks at high elevations. The pattern with field-collected seedlings (Plocher 1977) was similar; those from an ultramafic soil and from Blacklock soil on marine terrace sediments had the lowest concentrations of N, P, and K. In contrast, foliar nutrient concentrations of larger trees on productive soils near the northern end of the range were correlated with

Table 37—Macronutrient concentrations in foliage of natural trees of Port-Orford-cedar in its native range[1]

Major substrate	Size	Sample date	Number of sites (trees/site)	N	P	K	Ca	Mg	Ca:Mg	S	Reference 2/
				Percent						Percent	
Sedimentary	Trees > 15 cm	Sept.	3 1-2)	1.38 (1.25-1.5)	0.16 (.15-.16)	0.94 (.88-1.00)	1.46 (1.46)	0.17 (.15-.19	8.8 (7.7-9.1)	--	1
	Trees < 15 cm	Sept.	6 1-4)	1.23 (.90-1.85)	.14 (.11-.23)	.89 (.78-1.20)	1.30 .83-1.86]	.16 (.11-.26	8.4 (5.2-11.7)	--	1
	Saplings	Oct.-Nov.	3 2-8)	1.01 (.89-1.14)	.13 (.12-.15)	.61 (.56-.69)	.90 .50-1.20)	.18 (.11-.21	5.0 (4.4-5.8)	--	4
	Seedlings	March	1 (5-20)	1.07	.20	.69	.60	.20	3.0	0.11	3
Basalt	Trees < 15 cm	Sept.	1 (2)	1.31	.12	.67	1.34	.20	6.7	--	1
Ultramafic	Trees	October	1	0.93	.07	.40	.82	.40	2.1	.08	2
	Saplings	Oct.-Nov.	3 (10)	0.64 (.61-.67	.07 (.06-.07	.37 (.27-.42	.90 (.83-1.00)	.30 (.24-.37)	3.2 (2.3-3.7)	--	4
	Seedlings	March	1 (15-20)	0.57	.09	.58	1.11	.30	3.7	.11	3
Wet sand dune	Seedlings	March	1 (15-20)	1.22	.21	.84	.54	.25	2.2	.19	3
Marine terrace sediments	Seedlings	March	1 (15-20)	.68	.09	.53	1.24	.11	11.3	.09	3
Diorite 3/	Saplings	Oct.-Nov.	2 (10)	1.00 (.92-1.08)	.15 (.15)	.70 (.68-.71)	.98 (.88-1.08)	.21 (.12-.29)	6.2 (3.1-9.2)	--	4
Other igneous 4/	Saplings	Oct.-Nov.	2 (10)	.94 (.78-1.09)	.11 (.09-.12)	.51 (0.51)	1.70 (1.37-2.02)	.27 (.17-.37)	7.7 (3.7-11.7)	--	4

-- = no data available.

1/ Means are arranged by soil type and tree size; ranges of site means in parentheses.

2/ References: 1--Imper and Zobel (1983); 2--David McNabb, unpublished data on file, Dept. of Forest Engineering, Oregon State University; 3--Plocher (1977); 4--Zobel and Hawk (1980).

3/ One site included some ultramafic material.

4/ Both sites may have included some ultramafic material.

Table 38—Micronutrient and aluminum concentrations in the foliage of native Port-Orford-cedar saplings on four substrates sampled in October and November

Major substrate	Number of sites	Trees per site	Mn 1/	Fe 1/	Cu 1/	B 1/	Zn 1/	Al 1/
			Parts per million					
Sedimentary	3	2-8	423 (367-525)	254 (162-301)	7.3 (3.6-9.5)	18 (9-24)	55 (35-76)	226 (188-257)
Ultramafic	3	10	278 (178-400)	250 (214-308)	10.3 (7.0-13.6)	17 (14-20)	48 (42-54)	182 (124-286)
Diorite 2/	2	10	389 (157-620)	176 (165-187)	11.6 (6.0-17.2)	29 (27-30)	43 (40-46)	193 (88-298)
Other igneous 3/	2	10	626 (377-875)	113 (102-134)	4.7 (4.2-5.1)	29 (26-32)	50 (41-59)	122 (116-127)

1/ Range of site means in parentheses.

2/ One site included some ultramafic material.

3/ Both sites may have included some ultramafic material.

Source: Zobel and Hawk 1980.

Table 39—Macronutrient concentrations in whole seedlings of Port-Orford-cedar, 2 to 3 years old, grown in three nurseries, Washington and Oregon

(In percent)

Nursery	N	P	K	Ca
Greeley, WA	1.39	0.24	0.90	0.92
Wind River, WA	.57	.12	.74	.51
Corvallis, OR	.55	.12	.72	.53

Source: Youngberg 1958.

concentrations in the soil only when the soil content was low; overall correlations of foliar and soil concentrations were poor, with the best correlation being $r = 0.41$ for P (Imper and Zobel 1983). The only reported foliar levels of nickel and chromium are 56 and 1.12 p/m, respectively, from an area with ultramafic rock.[14] Nutrient concentrations of cultivated seedlings may vary drastically with soil type (table 39).

To test the effects of soil type and seed source on growth, Plocher (1977) transplanted native seedlings reciprocally from four contrasting soil types in Coos County onto the same four soil types in the greenhouse. Foliar nutrient concentrations after 8 months were affected by soil type in the greenhouse for K, Ca, and Mg, and by the source of the seedlings for all macronutrients except sulfur (tables 40 and 41). The most obvious effects of soil type were the high foliar K on sedimentary soils and the low Ca, high Mg, and low Ca:Mg ratio on ultramafic soils. The population most consistently different was from a wet dune and had relatively high values of foliar N, P, and K, a low Ca concentration, and a low Ca:Mg ratio (table 40).

Foliar nutrient values of seedlings grown in Taiwanese nurseries differed less among populations than in Plocher's work (Zobel and Liu 1979). Seedlings from four coastal seed trees had higher Ca and Zn in the leaves than did those from four seed trees on ultramafic soils (table 42); other nutrients were similar. There were no differences among trees within either of the two source areas; however, the nursery-grown seedlings differed in several ways from native populations growing in the regions where the seed came from (table 42).

Twenty-year-old planted trees at Bedgebury, England, had foliar nutrient values (in percent) of 0.92 N, 0.06 P, 0.30 K, 1.02 Ca, 0.19 Mg, and (in parts per million) of 140 Fe, 9900 manganese (Mn), and 300 sodium (Na) (Ovington 1956). Compared to native trees on sedimentary soils (tables 36 and 37), values of N, P, K, and Fe were all low, and Mn was extremely high.

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[14] Unpublished data of D. McNabb, on file at Department of Forest Engineering, Oregon State University, Corvallis.

Table 40—Concentrations of macronutrients in foliage of natural seedlings collected from four soil types, Coos County, OR, reciprocally transplanted to field-collected soils, and grown for 8 months in a greenhouse[1]

	Soil			
Population	Sedimentary	Dune	Ultramafic	Blacklock
	Nitrogen (percent)			
Sedimentary	1.04	1.02	0.93	0.93
Dune	1.14	.97	.98	--
Ultramafic	1.02	.67	.88	--
Blacklock	.92	1.23	1.07	1.13
	Phosphorus (percent)			
Sedimentary	.27	.33	.24	.15
Dune	.32	.35	.31	--
Ultramafic	.28	.19	.25	--
Blacklock	.24	.33	.29	.14
	Potassium (percent)			
Sedimentary	1.05	.85	.88	.83
Dune	1.28	.91	.99	--
Ultramafic	1.11	.63	.89	--
Blacklock	1.15	.68	.91	.84
	Calcium (percent)			
Sedimentary	.65	.59	.39	.70
Dune	.58	.52	.32	--
Ultramafic	.65	.68	.38	--
Blacklock	.62	.68	.38	.71
	Magnesium (percent)			
Sedimentary	.17	.25	.50	.17
Dune	.19	.29	.48	--
Ultramafic	.21	.25	.48	--
Blacklock	.18	.32	.49	.22
	Ca:Mg ratio			
Sedimentary	3.7	2.4	.8	4.1
Dune	3.0	1.6	.7	--
Ultramafic	3.2	2.4	.8	--
Blacklock	3.5	2.7	.8	3.2

-- = no data.

[1] Foliar sulfur concentrations varied from 0.04 to 0.26 percent. "Blacklock" soils developed on marine terrace deposits and support only slow growth. Significance of population and soil is given in table 41.

Source: Plocher 1977.

Table 41—Significance of population and soil type in affecting foliar nutrient concentrations of Port-Orford-cedar seedlings collected in the field and grown on three field soils in the greenhouse[2]

	Source of variation		
Nutrient	Soil	Population	Soil x population
Nitrogen	NS	**	**
Phosphorus	NS	**	**
Potassium	**	**	**
Calcium	**	**	NS
Magnesium	**	*	**
Sulfur	NS	NS	NS

NS = not significant; * = significant at 0.05 level; ** = significant at 0.01 level.

1/ Data are in table 40. Results from Blacklock soil were not included in the statistical analysis.

Source: Plocher 1977.

Table 42—Nutrient concentrations, as sampled in July, in 17-month-old nursery seedlings of Port-Orford-cedar grown in Taiwan

Source 1/	N	P	K	Ca	Mg	Ca:Mg	Mn	Fu	Cu	B	Zn	Al
	Percent						Parts per million					
Nursery Seedlings:												
Low elevation--Coastal (Coos County)	1.69 (1.61-1.82)	0.35 (.32-.40)	0.54 (.49-.58	0.62 (.60-.65)	0.17 (.16-.18)	3.6 (3.4-4.1)	745 605-854)	766 (620-909)	19 (16-23)	14 (12-16)	120 (117-124)	780 (622-927)
High elevation--Interior (Josepnine County)	1.70 (1.60-1.83)	.33 (.25-.37)	.64 (.55-.75	.55 (.51-.59)	.16 (.14-.21)	3.6 (3.0-3.9)	685 616-800)	687 (449-1428)	19 (13-27)	15 (13-18)	102 (88-112)	817 (418-1317)
Native saplings 2/:												
Coos Co. Forest	1.14	.12	.68	.50	.11	4.4	367	162	3.6	9	76	188
Grayback 3/	.92	.15	.71	1.08	.12	9.2	620	187	17.2	27	46	298

1/ Each seed source included seedlings from four seed-trees; the range of seed-tree values is given in parentheses. The only significant differences between sources are for Ca and Zn.

2/ Data for native saplings in the areas where seed was collected are given for comparison.

3/ Grayback is near the Josephine County seed source.

Source: Unpublished data on file, Department of Botany and Plant **Pathology,** Oregon State University, Corvallis; and Zobel and Liu (1979).

Foliar nutrients of potted plants can be quite different from those of forest trees. The cultivar 'Columnaris' in three fertilizer treatments (Besford and Deen 1977) had values (in percent) of 2.65-3.77 N, 0.46-0.51 P, and 1.43-1.93 K; all are higher than any for native or nursery plants (tables 37 and 39). In contrast, the cultivar 'Pottenii' has values for N, P, and K that are similar to nursery seedlings.

Port-Orford-cedar usually has lower foliar concentrations of all macronutrients than the Taiwanese species of ***Chamaecyparis*** grown in the same nursery, but higher Zn and aluminum (Al) (Zobel and Liu 1979). Native trees of Port-Orford-cedar have higher K in the foliage than cooccurring western redcedar and, usually, lower Ca:Mg ratios (Imper and Zobel 1983).

Differences between Port-Orford-cedar and Pinaceae are more extensive. In general, Port-Orford-cedar foliage has lower concentrations of N, P, Mn, and B, but higher concentrations of Ca, Fe, Copper (Cu), and Zn than does Pinaceae in the Pacific Northwest (Ovington 1956, Youngberg 1958, Zobel and Hawk 1980, Zobel and Liu 1979) (see tables 16 and 17). Cedar often has a higher Ca:Mg ratio, but results vary somewhat with the situation.

Effects on growth.—No critical or deficient levels of nutrients have been determined for Port-Orford-cedar, although poor mineral nutrition is said to delay development of mature foliage of Cupressaceae (Rehder cited by Woycicki 1954). In one experiment (Plocher 1977), however, variation of growth within four populations across the range of soils was most closely associated with foliar concentration of K, which ranged from 0.80 to 1.15 percent. Regressions including only K accounted for 64 to 95 percent of the variation in height growth. Addition of most other nutrients to the regression was significant; the final equations accounted for 97-99 percent of the variation. In equations for three of four populations, Ca and N were most important besides K. Variation in growth among populations on a single soil was not closely related to foliar K; the nutrients best related to growth were: (1) sedimentary soil—N, K, Mg (77 percent of variation accounted for); (2) ultramafic soil—P, Mg, Ca (67 percent); and (3) dune soil—P, Mg, K, Ca (92 percent).

In poorly growing English plantations of Port-Orford-cedar, mulching increases height fivefold (Leyton 1955), and reduces chlorosis (Weatherell 1953). In one case (Leyton 1955), the mulched trees had 2.49 percent N and 0.25 percent P in the foliage, compared with 0.59 and 0.06 for the control. Growth probably reflected the improvement in nutrition, although better water relations were thought to be the primary cause.

In New Zealand, cedar grows better where it adjoins or is mixed with plantations of pine than in pure populations (Weston 1971, personal observations of Lewis F. Roth).

In the examples cited above, growth of Port-Orford-cedar increased with higher foliar N and K, and usually with higher P. Sometimes, however, concentration of Ca was higher in slower-growing trees, and Mg and S usually were higher (Imper 1981, Leyton 1955, Plocher 1977).

Increasing foliar iron concentration above 34 p/m increased growth and reduced chlorosis of the cultivars 'Columnaris' and 'Pottenii' (Besford and Deen 1977), despite the fact that some macronutrient concentrations declined. In 'Columnaris', Fe at 256 p/m (a concentration common in natural and forest nurseries; see tables 37 and 41) reduced growth. Levels of an iron-dependent enzyme (peroxidase) were much more sensitive indicators of foliar iron than were plant size or chlorosis.

Removal of nutrients by seedling crops (producing 5123 to 6031 kg/ha dry weight) was: N—29-75 kg/ha; P—7-13; K—38-47; and Ca—26-48 (Youngberg 1958).

Fertilization of Port-Orford-cedar stands has apparently not been attempted. Fertilizing *Charnaecyparis* ***obtusa*** plantations in Japan has proven to be economically feasible (for example, Haibara and others 1977).

Shade Tolerance

Minore (1979) lists Port-Orford-cedar as having moderate shade tolerance. He classifies it among its usual competitors as more tolerant than incense-cedar, sugar pine, Douglas-fir, and western white pine, and less tolerant than Shasta red fir, Brewer spruce, white fir, Sitka spruce, grand fir, western redcedar, and western hemlock (species are listed in order of increasing shade tolerance). Minore's conclusion represents a compromise among the varying opinions about shade tolerance of Port-Orford-cedar. Franklin and Dyrness (1973, p. 92-93) conclude that it ". . . is not capable of reproducing under closed forest conditions and is replaced by more tolerant associates . . . ." But planted seedlings successfully grow up through gorse and bracken (Hermann and Newton 1968, Krygier 1958) and the British found that ". . . it stands shade well . . ." and ". . . can be used for underplanting other conifers or for bringing in under hardwood scrub" (Macdonald and others 1957, p. 48). Baker (1945, p. 434), referring to a greenhouse experiment, comments that " . . . its ability to survive and to put on height growth in low light is phenomenal." Others indicate that its shade tolerance varies: "Moderately tolerant of shade throughout life, but especially tolerant of heavy shade in early stages" (Sudworth 1908, p. 175); and "Competitive ability" (defined to include shade tolerance) is said to be high on wet sites in California *Abies concolor* zone forests, but only intermediate on mesic sites in the *Abies magnifica* zone (Sawyer and Thornburgh 1977).

Our recent work (Hawk 1977, Zobel and Hawk 1980) suggests that Port-Orford-cedar is the most shade-tolerant conifer species throughout much of its range, and that it reproduces more successfully in old-growth forests than is indicated by Franklin and Dyrness (1973). The cedar probably has a somewhat higher relative tolerance than is indicated by Minore (1979).

Community analyses by Hawk (1977) show Port-Orford-cedar reproducing well in all communities he recognized and contributing 17-93 percent of conifer saplings and 26-62 percent of conifer seedlings (seedlings are <1 meter tall); cedar's proportion of the reproduction was lowest in the most open and most shaded communities (tables 43 and 44). Reproduction of western hemlock considerably exceeded Port-Orford-cedar in importance only in the swordfern community, which was the most shaded community. Even there, the cedar maintained 118 saplings and 313 seedlings per hectare. Where white fir grows with the cedar, the two have similar amounts of reproduction (table 43).

Table 43—Percentage of saplings and seedlings of Port-Orford-cedar, western hemlock, and white fir in Hawk's (1977) eight major forest communities

	Saplings				Seedlings			
Community	Total	Port-Orford-cedar	Western hemlock	White fir	Total	Port-Orford-cedar	Western hemlock	White fir
	number/ha	------ percent ------			number/ha	------ percent ------		
Swordfern	810	27	70	--	1214	26	67	--
Rhododendron	373	29	32	--	873	44	50	--
Beargrass	762	57	28	--	1019	53	27	--
Tanoak	1082	93	--	--	1033	62	--	--
Mixed pine	791	17	--	14	1076	30	--	0
White fir-hemlock	715	34	14	31	1280	31	20	24
White fir	2293	55	--	21	1820	37	--	36
Mixed fir	1165	40	--	39	1042	33	--	36

-- = species absent.

Table 44—Light reaching live conifer saplings in six communities, expressed as a percent of light in the open

(In percent)

	Species				
Community	Port-Orford-cedar	Western hemlock	Douglas-fir	Pine spp.	White fir
Swordfern	0.7	0.6			
Tanoak	2.9		9.5	8.7	
Mixed pine	37.1		44.8	33.3	
Terrace	3.4		4.9		
White fir	2.1			1.2	3.6
Mixed fir	5.4				5.7

Source: Zobel and Hawk 1980.

Unpublished data from eleven 375-m^2 plots are cited by Franklin and Dyrness (1973) and also are presumably used by Daubenmire (1969) and Franklin and others (1972, sections CO and PO). The data show four plots where Port-Orford-cedar considerably exceeded western hemlock (averaging 36 cedar to 4 hemlock) in numbers of small trees (<10 cm d.b.h.), two plots where hemlock dominated (average 1 cedar to 97 hemlock), three where both were important (26 cedar to 21 hemlock), and two where neither was important (1 cedar to 4 hemlock). This seems to indicate neither consistent dominance of hemlock nor failure of Port-Orford-cedar. Port-Orford-cedar had more reproduction than grand fir in the five plots where they both grew (averaging 30 cedar to 13 fir).

Light was measured in the tops of understory saplings of six of Hawk's (1977) major communities and in one stream terrace stand (table 44). Incense-cedar, Jeffrey pine, and Douglas-fir received significantly more light than did Port-Orford-cedar on the same sites; other species were not statistically different from Port-Orford-cedar (Zobel and Hawk 1980). Port-Orford-cedar saplings were growing with less than 1 percent of full sunlight in the swordfern community. There is evidence, however, that Port-Orford-cedar cannot survive in the darkest microsites. Dead cedar saplings in two stands averaged 0.2 and 0.4 percent light compared to 0.7 and 2.5 percent, respectively, for living ones (Zobel and Hawk 1980). Young, dense cedar stands have little reproduction of any kind. One mixed stand with Sitka spruce, western hemlock, and Douglas-fir had 0.9 percent light reaching the forest floor and no tree reproduction. Planted seeds germinated and established better there than in more open sites, but no seedlings survived the second growing season (Zobel 1980). Similar measurements of other species in southwestern Oregon indicate lower limits for light for white fir are similar to, and for Douglas-fir similar to or usually above, those for Port-Orford-cedar (Atzet and Waring 1970, Emmingham and Waring 1973).

In coastal Coos County, cedar, western hemlock, and Sitka spruce all establish and grow up through dense red alder; cedar can do this in other areas also.

Our evidence from the field suggests that Port-Orford-cedar usually reproduces as or more effectively in the shade than any of its major associated conifers; the only exception is western hemlock in the most mesic old forests. Even there, Port-Orford-cedar grows at low light intensities and maintains a sizable population of reproduction and small trees (Hawk 1977).

The only experimental study of effects of shading on Port-Orford-cedar (Baker 1945) included several associates usually considered to be less shade tolerant: Douglas-fir, Jeffrey pine, incense-cedar, and redwood. After emphasizing the complexity of seedling responses to shade, Baker concluded that, "Ability to maintain life in the shade is measurable only by — ability to maintain life in the shade" (p. 433). Port-Orford-cedar reacted similarly to the pattern theoretically expected for a tolerant tree and had higher survival at the lowest light intensity than the other species. Its ratio of top height to dry weight in dense shade ("index of slenderness") was the highest of all species. Dry weight gain of 100-day-old seedlings increased sevenfold, top:root ratio decreased from 3.0 to 2.2, and height increased from 65 to 120 mm as light intensity for growth was increased from 10 percent to 70 percent of full light.

Baker (1945) also found that full light reduced survival of Port-Orford-cedar to about half that in the deepest shade, as well as somewhat reducing growth. In the field, however, the species will establish well in the open (Franklin and Dyrness 1973, Hayes 1958, Sudworth 1908, Zobel and Hawk 1980).

Responses to Damaging Agents

Native diseases and insect pests.—Port-Orford-cedar is singularly free of attack by native pathogens and insects. Those described (Furniss and Carolin 1977, Hepting 1971, Shaw 1973, U.S. Department of Agriculture 1960) appear to be well integrated into the biological communities and unlikely to threaten productivity of the forest; none is fatal or apparently debilitating.

In some years, pink larvae of the Port-Orford-cedar midge, ***Janetiella siskiyou*** Felt, greatly reduce the seed crop. The midge occurs both in the natural range (Felt 1917) and in Europe (Gagne 1972). The seeds contain a substance that acts as a juvenile hormone on some (nonendemic) insects (Jacobson and others 1975).

The major insect pests are cedar bark beetles ***(Phloeosinus*** spp.), which attack dying or dead trees in large numbers (Kliejunas and Adams 1980, Roth and others 1957, Wright and Mitchell 1954). They may kill some live trees where root rot mortality or large amounts of slash have allowed high beetle populations to develop, and where cedars at the edge of harvest units are stressed. due to exposure. Although cedar bark beetles have little impact on forest productivity, their effects complicate diagnosis of root rot and require caution with some stand management decisions. Port-Orford-cedar is listed as a host of ***P. sequoiae*** Hopkins, which is more aggressive than most species of the genus (Furniss and Carolin 1977).

The amethyst cedar borer ***(Semanotus amethystinus*** [Le Conte]) and the cedar tree borer (***S. ligneus*** [F.]) attack boles and large limbs of the species. The blazed tree borer (***Serropalpus substriatus*** Haldeman) bores into dead trees (Furniss and Carolin 1977). Bark from Port-Orford-cedar stimulates feeding of the white pine weevil ***(Pissodes strobi*** Peck) less than does the bark of most conifers (Alfaro and Borden 1982). Other insects occur, apparently without major effects, on cultivated specimens (Carter and Young 1973, Wheeler and Henry 1977). Spider mites may become important on some cultivars; the mites feed on the underside of foliage during hot, dry weather (den Ouden and Boom 1965).

The only significant native pathogen is an unidentified fungus that causes a destructive, honeycombing, white pocket rot in the tops of old timber. This rot may extend downward through the bole, even to stump height, to involve several logs and result in extensive cull. The fungus produces no external indicators; consequently, estimating deductions from merchantable volume must rely ,on the judgment of experienced cruisers and data from adjacent or comparable stands.

Introduced diseases.—Damage to Port-Orford-cedar by introduced pathogens is extensive. Although these pests are not numerous, two soil-borne aquatic fungi, ***Phytophthora cinnamomi*** Rands and ***Phytophthora lateralis*** Tucker and Milbrath, cause fatal root rots. ***Phytophthora cinnamomi*** is distributed worldwide in favorable habitats on hundreds of species of trees and shrubs, including Port-Orford-cedar and most of our commercial conifers. The fungus requires some summer irrigation (Roth and Kuhlman 1966) and, consequently, is poorly suited to the forest habitat of the Pacific Northwest. It is a problem in nurseries and landscape plantings.

Phytophthora cinnamomi appears to have originated in southeast Asia (Shepherd 1975). It is a significant problem in Europe where horticultural Port-Orford-cedar continue to be produced in substantial numbers. Modern fungicides (furalaxyl and aluminum ethyl phosphate) for aquatic fungi (Phycomycetes) are effective in greenhouse studies (Bertus and Wood 1977, Smith 1980).

Phytophthora lateralis appears to be restricted to *Charnaecyparis* along the central west coast of North America and is ideally suited to both climate and soils (Trione 1959). *Phytophthora lateralis* is destructive in the native forest (Roth and others 1957), in horticultural nurseries, and to specimen and windbreak trees (Roth and others 1972, Torgeson and others 1954). Although no USDA Forest Service nursery is known to be contaminated,[15] the prolonged absence of cedar from these nurseries makes it difficult to monitor the condition. The fungus does occur in forest nurseries in British Columbia.[16]

Port-Orford-cedar cannot be managed to produce future rotations without dealing effectively with *Phytophthora lateralis* root rot. Correct management depends on a sound understanding of the disease; present knowledge of *P. lateralis* and the resultant root rot is summarized in Chapter 7 and recommendations for management are presented in Chapter 8.

Animals.—Animal damage to Port-Orford-cedar can be severe, but apparently is not usually a problem; no general conclusion about relative susceptibility seems justified from the limited data. James (1958, p. 2) reports that "Port-Orford-cedar is more heavily browsed by animals than are other common associates—thus verifying a common observation." He found 19 percent of the trees in plantations had at least moderate damage (mostly from deer and elk) as compared to 8 percent for Douglas-fir. In one plantation north of the range, 70 percent of cedar was damaged and only 20 percent of Douglas-fir (Ruth 1957). Another report (Schenck 1907, p. 93) says that mice eat the bark or roots and in general "game are very bad." Other authors report the opposite results: Cedar escaped or was less damaged, especially by rabbits, where Douglas-fir was destroyed or greatly deformed, both inside the normal range (in dense cover) (Hermann and Newton 1968, Lavender 1953) and outside the range (Staebler and others 1954). In a Washington plantation (Staebler and others 1954), 4-year height of deformed cedars was 14 percent less than for apparently undamaged trees (compared to 32 percent for Douglas-fir and 44 percent for western hemlock); however, intact cedars were still shorter than damaged Douglas-fir. More recently, in contrast to James' (1958) comment, forest managers have reported no important animal problems in naturally regenerated stands. Mountain beaver eat the foliage, wood rats and porcupines remove the bark, and elk and deer browse; however, there is no apparent preference for cedar and in some areas there is obviously less damage to cedar than to Douglas-fir. Some loss of small seedlings occurs, apparently to small mammals and birds (Moore 1940).

Although some small rodents apparently dislike the seeds of Port-Orford-cedar (Moore 1940), squirrels do harvest the cones and remove the seeds (Zobel 1979).

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[15] Unpublished reports, 1958-1960, Northwest Forest Pest Action Council, Portland, Oregon.

[16] Unpublished report, 1954, J.P. Salisbury, on file at Canada Department of Agriculturs, Forest Biology Laboratory, 409 Federal Building, Victoria, BC, Canada.

Table 45—Freezing resistance (temperature low enough to kill) of twigs collected in winter from *Chamaecyparis* species and some conifers associated with Port-Orford-cedar that were grown in Japan

Species	Seed source	Killing temperatures "Bud" 1/	 Leaf	 Twig	Growth in Hokkaido
		- - - - - - - - °C	- - - - - - - -		
Port-Orford-cedar	California	-15	-20 to -25	-25 to -30	Impossible
Alaska-cedar	USA	--	-20	-25	--
Chamaecyparis obtusa	Japan	-20	-20 to -35	-25 to -30	Bad
Chamaecyparis pisifera	Japan	-20	-20 to -30	-20 to -25	Bad
Western redcedar	Washington	-20 to -30	-30 to -40	-25 to -40	Impossible
Redwood	California	-15	-15 to -20	-15 to -20	Impossible
Douglas-fir	Washington	-20 to -25	-20	-20 to -25	Bad
Grand fir	British Columbia	-20	-50	-50	Bad
Sitka spruce	Washington	-20	-30	-30	Bad

-- - no data available.

1/ "Bud" = apical meristem.

Source: Sakai 1982, Sakai and Okada 1971.

Extreme temperatures.—The shoot apical meristems of hardened Port-Orford-cedar die at –15 °C in a laboratory test of cold hardiness (table 45); leaves and twigs are somewhat hardier. Conifer associates (from more northern sources) resist slightly lower temperatures, and Japanese ***Chamaecyparis*** have slightly more resistant apical meristems (table 45).

Killing of Port-Orford-cedar by frost has occurred in several areas. Low mortality and considerable top-kill occurred in plantations along the northern Oregon coast at 290 m; no damage occurred at lower elevations (Krygier 1958). Plantation trees in Washington were killed or severely damaged by severe cold in November 1955 when minimum temperatures were about –14 °C; the blue variety 'Allumi' "showed resistance" (Duffield 1956). Sitka spruce was damaged less than the cedar. Port-Orford-cedar has been killed by cold in Europe in several instances (Day and Peace 1946, Forestry Commission 1965, Hayes 1958, Macdonald and others 1957, Welch 1966). Other reports stress its relative hardiness there; winter temperatures as low as –26 °C have not harmed Port-Orford-cedar in Britain (Dallimore and Jackson 1966). Much damage to the cedar is associated with dry, windy weather in combination with the cold (Duffield 1956, Forestry Commission 1965, Welch 1966).

In 1935, a May frost that moderately damaged Port-Orford-cedar and Douglas-fir severely damaged western redcedar, western hemlock, grand fir, and Sitka spruce in the same British plantation (Day and Peace 1946). Macdonald and others (1957, **p.** 48) state that "low temperatures in winter do not harm this tree," but there is more damage in spring. On the contrary, Sudworth (1908) considers it more resistant to late than to early frosts because it starts growth late. It is less frost hardy as a seedling (Sudworth 1908). The temperature necessary for damage, the most susceptible time of year, and the tolerance of Port-Orford-cedar relative to its associates all vary among reports.

There is little information about heat-tolerance of Port-Orford-cedar. Baker (1945) feels that reduced seedling survival in full light probably results from associated higher temperatures. The species grows and reproduces in open forests on serpentine, however, where maximum air temperatures (at 1 m) average 35 °C in the warmest month and exceed 40 °C several days each summer (Zobel and Hawk 1980).

Wind and snow.—Port-Orford-cedar is able to withstand strong wind and although it can be damaged by wind with wet snow, it is not overly susceptible (Holubcik 1960, Macdonald and others 1957, Radu 1960). Stands partially killed by root rot are windthrown more than are healthy ones. The species does grow naturally in areas having a persistent winter snowpack (see table 3).

Fire.—Large Port-Orford-cedar trees have thick bark and often bear fire scars. In some cases, fire has removed all except a thin, incomplete outer shell of wood and bark at the tree base (for example, fig. 63 in Franklin and Dyrness 1973), yet the trees remain healthy and standing for decades, probably centuries. Some smaller scars heal completely. Fire scars are usually not invaded by rot or insects.

Even as a pole-sized tree, Port-Orford-cedar has a good chance of surviving a ground fire. Its resistance is said to be less than that of Douglas-fir but greater than that of true firs and hemlock.[17] Silvicultural underburning of pole stands may be feasible with cedar. Smaller trees are readily killed by fire (Hayes 1958) and do not appear to be any more fire-tolerant than do associated species. Fire resistance is considered to be "medium" in California, less than that of ponderosa pine, Jeffrey pine, sugar pine, Douglas-fir, and incense-cedar (Sawyer and Thornburgh 1977).

Repeated fires have occurred in many old stands (Hawk 1977). For example, one stump (54 cm diameter, 285 years old) near the northern end of the species' range had fire scars at 35, 183, and 228 years. The fire frequency in the upper Illinois Valley was greater than that in the Oregon Coast Ranges (see footnote 17). A regime of repeated fires that killed part of the overstory probably increased the proportion of cedar in many stands because it could survive fire better than other shade-tolerant species and could establish under the residual overstory better than Douglas-fir (Hawk 1977). More frequent fires in other areas appear to favor Douglas-fir (Atzet 1979), which probably attains thick bark at a younger age but is

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[17] Personal communication, 1981, T. Atzet, Area Ecologist, USDA Forest Service, Grants Pass, Oregon.

Table 46—Tree density in 1980, by diameter size classes, in the Nickel Creek Burn, Coos County, OR, 28 years after the fire, on a relatively poor, high-elevation site on serpentine soil

(In trees per hectare)

Species	Diameter class 0-2 cm	3-7 cm	8-12 cm	13-17 cm	18-27 cm	28-53	53+ cm
Port-Orford-cedar	1546	57	20	20	30	44	12
Western white pine	494	138	59	17	25	7	2
Douglas-fir	205	30	82	--	--	7	2
Western hemlock	198	10	--	--	7	2	--

-- = absent.

Source: .Unpublished data on file, Powers Ranger District, Powers, OR.

less shade-tolerant than cedar. Following fire in coastal Oregon, Port-Orford-cedar is the first conifer to reinvade (Sargent 1884). It often dominated the volume remaining in recent burns (see footnotes 6 and 7) probably because dead trees retained their merchantability for many years. Data from one partially killed mixed stand on peridotite show that western white pine and Oouglas-fir dominate the larger regeneration, although the smallest size class is predominantly cedar (table 46).

Part of the fire resistance of Port-Orford-cedar may be due to the undulating interface between wood and bark near the tree base, which causes the bark to vary in thickness. The very thick areas of bark almost surely allow partial survival by the cambium in fires that would completely kill the cambium of a tree with the same average bark thickness evenly distributed around its circumference.

After logging, dead Port-Orford-cedar twigs do not shed their needles and the fine slash does not collapse onto the forest floor as does that of Pinaceae. The litter dries quickly, has good aeration, and ignites explosively when dry.[18] Cedar litter in standing timber also appears to burn faster than other litter types.

Air pollution.—Port-Orford-cedar can withstand moderate air pollution but grows poorly where pollution is heavy (Macdonald and others 1957). The sensitivity of Port-Orford-cedar to sulfur dioxide has been tested (Enderlein and Vogl 1966). Exposure for 57 hr at 1.9 p/m resulted in only slight visible injury. Such treatment drastically reduced photosynthesis on the second and third days of exposure, however; it had less effect on Douglas-fir and none on western redcedar. Port-Orford-cedar is said to be sensitive to damage by nitrogen dioxide but ***Chamaecyparis*** spp. are listed as relatively insensitive to NO_3 (Bernatzky 1978).

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[18] Personal communication, 1981, personnel of USDA Forest Service, Powers Ranger District, Powers, Oregon.

Vegetative Phenology

Twig elongation of Port-Orford-cedar, as for all Cupressaceae, follows a cycle different from that of Pinaceae. Although the apex is cutinized, there are no bud scales. There is no late-season formation, inside the protection of a bud, of leaves and internodes that can then rapidly expand the following year. In Berkeley, CA, south of the native range, slow growth continues all year, and there is no complete winter dormancy (Al-Sherifi 1952, Erspamer 1953). “However, the apical meristem appears to experience a kind of cessation in its growth, which is characterized by very infrequent mitotic divisions, small size of the apex and virtual cessation of leaf initiation” in the winter. “From the middle of March to September, one may observe numerous mitotic figures, active leaf formation, and the large size of the apical meristem” (Al-Sherifi 1952, p. 19).

Shoot expansion occupies much of the growing season. A comparison of leading shoots of many young conifers in Great Britain (Mitchell 1965) shows that Port-Orford-cedar start growth slowly and “hesitantly,” but then grow steadily for a long period, the growing season lasting from May 8 to September 5. Port-Orford-cedar starts growing within a week of most associated conifers; the exceptions are lodgepole pine (3½ weeks earlier) and incense-cedar (3½ weeks later). Growth for Port-Orford-cedar ends later than for all species with which it naturally grows. Lengths of growing season (days) in Great Britain were: western redcedar, 123; Port-Orford-cedar, 120 (range 75-147 days); western hemlock, 102; Sitka spruce, 87; lodgepole pine, 69; grand fir, 63; Douglas-fir, 56; and white fir, 41.

Lateral twig elongation of native saplings is highly variable (Zobel 1983). At sites with more moderate, maritime climates, growth lasted the longest; at hot sites it usually started at a similar time but ended earlier than near the coast; and at cold sites it both started and ended later (table 47). The time for elongation from *5* to 95 percent of final length ranged from about 80 days at the hottest site to over 150 days in the open in coastal Coos County, and occupied from 35 to 89 percent (mean, 62) of the frostless season in 1975. At the Coos County Forest, significant elongation continued into October. At sites with a similar mean temperature, growth was earlier in California than in Oregon (fig. 17).

The acceleration of growth of native Port-Orford-cedar saplings in the spring was closely related to air temperature (Zobel 1983). Lateral twigs of cedars in the ***Tsuga heterophylla*** zone grew at average day temperatures of about 4.5 °C; those in other zones grew only above 6 °C. Growth of trees in the cold ***Abies*** *concolor* zone increased faster with rising temperature than did growth in other zones. Elongation of the leaders was less clearly related to environment than was elongation of the lateral branches. Lateral twig elongation of Douglas-fir, western hemlock, and white fir lasted a shorter time than did that of cedar on the same sites: hemlock usually started later; Douglas-fir was earlier on some sites and later on others; and white fir started about the same time as the cedar.

There is no evidence of significant twig elongation by native Port-Orford-cedar during late fall and winter (Imper 1981, also see footnote 10).

Table 47—Mean dates for native seedlings of Port-Orford-cedar in each vegetation zone to complete 5, 30, 70, and 95 percent of lateral twig elongation, with periods required for 30-70 percent and 5-95 percent elongation

		Date reached						Days required			
		5 percent		30 percent		70 percent		95 percent	30-70 percent		5-95 percent
Vegetation zone	Number of populations	1975	1976	1975	1976	1975	1976	1975	1975	1976	1975
Tsuga heterophylla	2	May 5	May 9	June 9a 1/	June 13a	July 22a	July 22	Aug. 29	43a	40a	116
Mixed evergreen	6	May 4	May 5	June 7a	June 14a	July 8a	July 19	Aug. 13	31b	35ab	97
Abies concolor	3	--	--	July 13b	July 1b	Aug. 5b	July 29	Sept. 2	23b	28b	--

-- - no data available.

1/ Means in the same column with dissimilar letters are statistically different (0.05 level).

Source: Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.

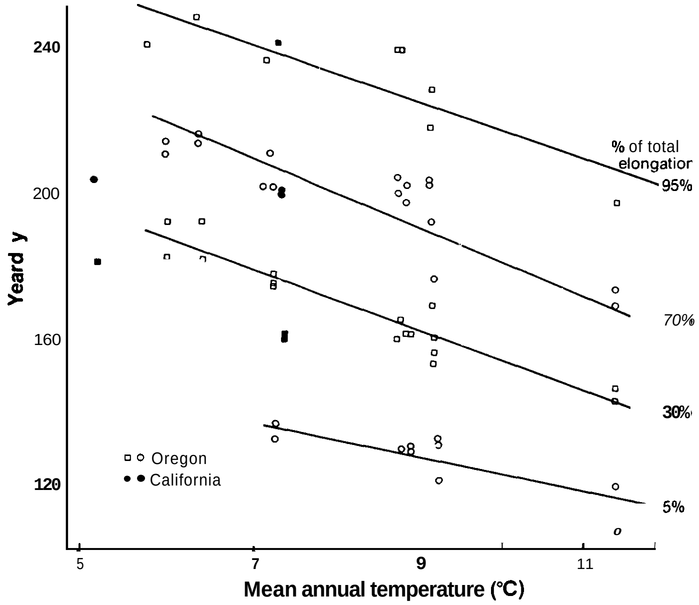

Figure 17.—Day of the year when twig elongation reached 5, 30, 70, and 95 percent of final length at nine sites varying in mean annual temperature (January 1 is year-day 1). Regression lines are calculated for Oregon stands only. Each symbol represents the mean of several trees at one site. (Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

Timing of twig elongation was determined for populations of rooted cuttings grown together in a common plant bed; timing varied much less than that of populations in the field (Zobel 1983). Differences among populations were not significant. Elongation varied drastically in the 2 years sampled; elongation from 5 to 95 percent of total growth lasted 102-117 days in the first year and 160-175 days in the second. Differences among field populations apparently represent primarily the effects of local environment.

Twig elongation of seedlings transplanted into the greenhouse in March was still continuing 34 weeks later (Plocher 1977), but rooted cuttings kept in the greenhouse several years may elongate little, if at all, until placed outside.

The late, long-lasting twig elongation of Port-Orford-cedar may have important ecological consequences for the cedar (Zobel 1983). Slow, late growth may increase cedar's susceptibility to drought because new foliage is exposed all summer, and successful apical function and cell enlargement require high water potentials through much or all of the summer. Species that continue to grow into late summer can increase the current year's growth in response to late season management to improve the environment (Mitchell 1965).

Growth and **Size**

Height and branch length.—New seedlings grow very little under a natural canopy. Height above the cotyledons averaged 3 mm, 14 mm, and 27 mm (maximum 52) after one, two, and three seasons, respectively, (Zobel 1980). Growth in the open is faster, with total heights of 36 and 79 mm for the first and second year, respectively, in the Port-Orford-cedar Experimental Forest (Hayes 1985).

Seedlings may grow much more in greenhouse or nursery conditions. Greenhouse-grown seedlings reached 25 to 100 mm (maximum 350 mm) above the cotyledons (which were 9 to 22 mm above the soil) in the first year (Franklin 1961). Height of 100-day-old seedlings in nutrient solution was 65 mm at 10 percent of full light and 120 mm at full light (Baker 1945). Nursery seedlings 14.5 months old averaged 137 ± 56 mm tall (range 50-300 mm) in Taiwan (Liu and others 1975).

Height growth of natural saplings in the understory was estimated by aging young trees and by measuring sapling height increment for 2 or 3 years. The change in height with age varied considerably among communities both under a canopy and in clearcuts (figs. 18 and 19; table 48). Growth in the swordfern community was fastest, followed by that in open forest on Blacklock soil. Growth in clearcuts during the sapling stage was two to three times as fast as in the forest. Other species sampled at the same sites grew similarly or slower: Douglas-fir and western hemlock averaged *5* and 4 years to breast height, respectively, in clearcuts in the swordfern community; western hemlock averaged 16 years in swordfern community forests; white fir averaged 29 years in the three ***Abies*** *concolor* zone communities; and in the mixed pine community, Jeffrey pine averaged 33 years and Douglas-fir 31 years to reach breast height.

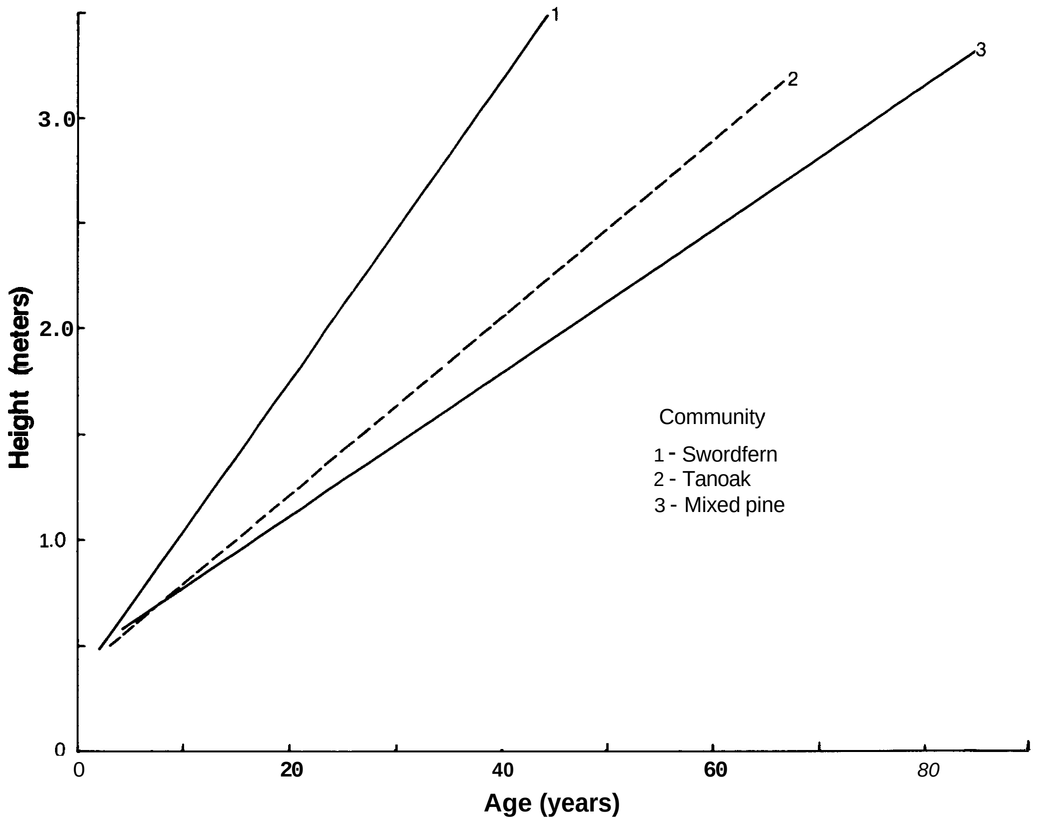

Figure 18.—Height-age relationships of Port-Orford-cedar saplings in three low-elevation forest communities. Regression equations for the communities (y=height [meters], x=age [years]) are: swordfern ($n=35$, $r^2=0.67$): $y=36 + 7.0x$; tanoak ($n=33$, $r^2=0.80$): $y= 43 + 3.4x$; mixed pine ($n=44$, $r^2=0.52$): $y = 38 + 4.2x$. (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Cowallis.)

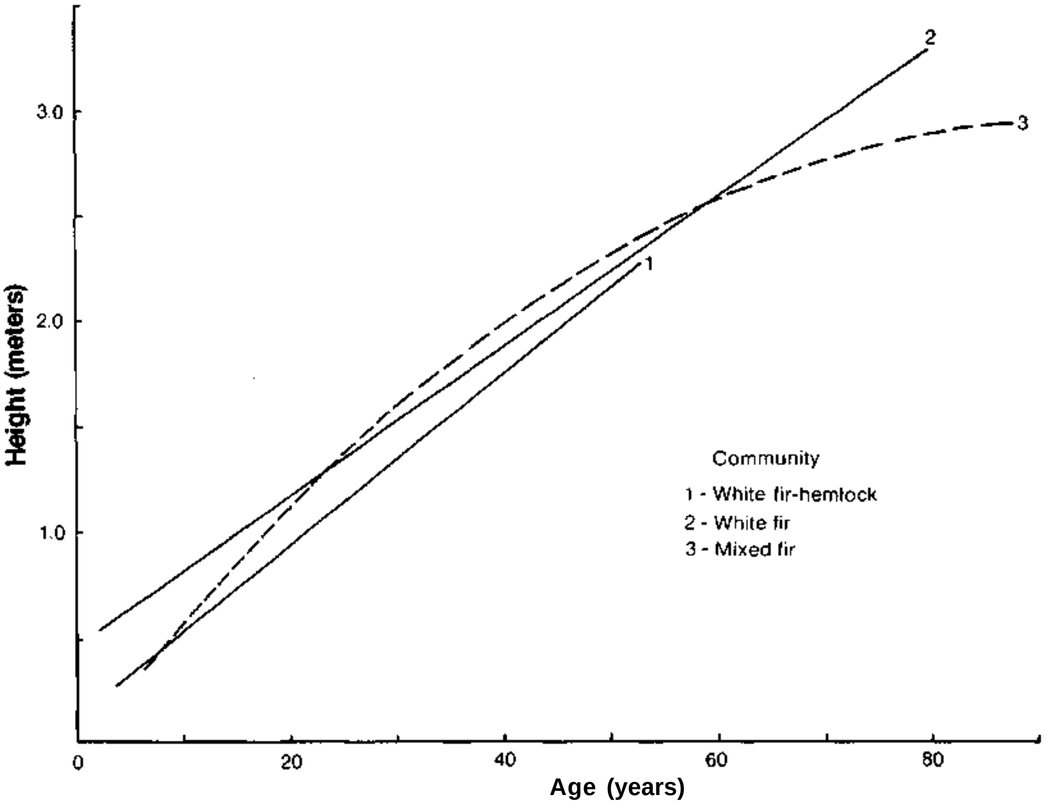

Figure 19.—Height-age relationship of Port-Orford-cedar saplings in three communities of the *Abies concolor* zone. Regression equations for the communities are: white fir-hemlock (n=43, *14=0.77):* $y = 12 + 4.1x$; white fir (n=82, r2=0.76): $y = 46 + 3.6x$; mixed fir (n=49, ^=0.69): $y = -2.5 + 6.4x - 0.035x^2$. (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

Table 48—Time necessary for natural Port-Orford-cedar saplings to reach breast height (137 cm) as measured from ring counts and as estimated from a regression of total height on age[1]

(In years)

	Natural forest		Clearcut	
Community [2]	Measured	Estimated	Measured	Estimated
Swordfern	12	14	4	5
Coastal terrace (Blacklock soil)	19	18	--	--
Tanoak	30	28	--	--
Mixed pine	28	24	--	--
White fir-western hemlock	27	31	--	--
White fir	27	26	--	--
Mixed fir	24	26	11	11

-- = no data available.

[1] Sample sizes are 9-27 per community (measured) and 26-82 (estimated from regressions), except for 11-21 in clearcuttings.

[2] As defined in Chapter 4.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Elongation of terminal shoots of natural understory saplings varied considerably among sites within zones and among years (table 49). Terminal elongation was much greater in the open at Coos County Forest, 432 mm in 1976, than in the understory (table 49). Because of the cedar's growth form, however (see Chapter 5), some of the terminal elongation (as measured here) may not contribute to height growth.

Terminal elongation of small trees in a British plantation averaged 290 mm per year (range 150 to 690); maximum weekly increment was 50 mm. Growth was greatest in wetter years (Mitchell 1965).

Seedling height growth in a common environment varies considerably with the seed source and growing conditions. Height growth of native seedlings transplanted to the greenhouse varied with the soil type from which the seedlings were collected and the soil type in which they were grown (table 50). The coastal dune seedlings continued rapid elongation longer than the others (Plocher 1977). Height growth of rooted cuttings measured during their first and third years after outplanting in a plantbed in Corvallis, OR, varied twofold to threefold with source (table 51).

Table 49—Elongation of terminal shoots of native understory Port-Orford-cedar saplings, by vegetation zone and year

Zone	Number of sites	Elongation[1] 1975	Elongation[1] 1976
		----- Millimeters -----	
Tsuga heterophylla	1	28	28
Mixed evergreen	4 to 6	30 (19 to 39)	38 (24 to 62)
Abies concolor	1 to 2	13	43 (39 to 47)

[1] Range of site means in parentheses.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.

Table 50—Height increase of native seedlings from Coos County, OR, after transplanting into four field-collected soils in the greenhouse for 34 weeks[1]

(In millimeters)

Source of population	Soil: Sedimentary	Ultramafic	Dune	Blacklock
Inland sedimentary rock	199	105	41	21
Inland ultramafic	169	87	16	--
Coastal wet dune	234	153	43	--
Coastal Blacklock soil	174	107	31	25

-- - no data available.

[1] Variation is significant among populations, among soils, and with their interaction.

Source: Plocher 1977.

Table 51—Leader elongation of rooted Port-Orford-cedar cuttings grown in a plantbed in Corvallis, OR, first and third years after outplanting

Source of cuttings (location)	Elevation	Leader elongation	
		1976 1/	1978 2/
	Meters	---Millimeters---	
Coastal and montane			
coos co., OH	10-520	178	232
Blacklock soil, Coos Co., OR	140	176	154
Montane serpentine,			
Coos Co., OR	850	101	202
Josephine Co., OR	1300	58	119
Sacramento River, CA	580	110	187

1/ The two longest differ significantly from the shortest.

2/ The longest differs significantly from the shortest.

Source: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis; Zobel 1983.

Seedling height growth is stimulated by a long (16 hr) photoperiod and even more by addition of gibberellic acid; hormone-treated trees were 160 mm tall at 14 weeks. Growth continued at a 10-hr photoperiod and was not significantly increased by interruption of dark hours; both this and the response to the hormone were opposite the behavior of Sitka spruce (Bonnet-Masimbert 1971).

Height growth of Douglas-fir past the sapling stage exceeds that of cedar off serpentine soil; cedar is overtopped in most mixed stands at 20-25 years (Hayes 1958). In 8- to 26-year-old plantations (Hayes 1958, James 1958), annual height growth of unbrowsed Port-Orford-cedar averaged 0.35 m, only 68 percent of that of Douglas-fir; when browsed trees were considered, the difference was much greater. Height growth in plantations in coastal Oregon, but north of the range, varied from very poor, 0.76 m in 10 years (about half that of Sitka spruce) (Ruth 1957), to the best of any plantations known, 9.5 m in 19 years (taller than Sitka spruce and about the equivalent to native western hemlock) (Krygier 1958).

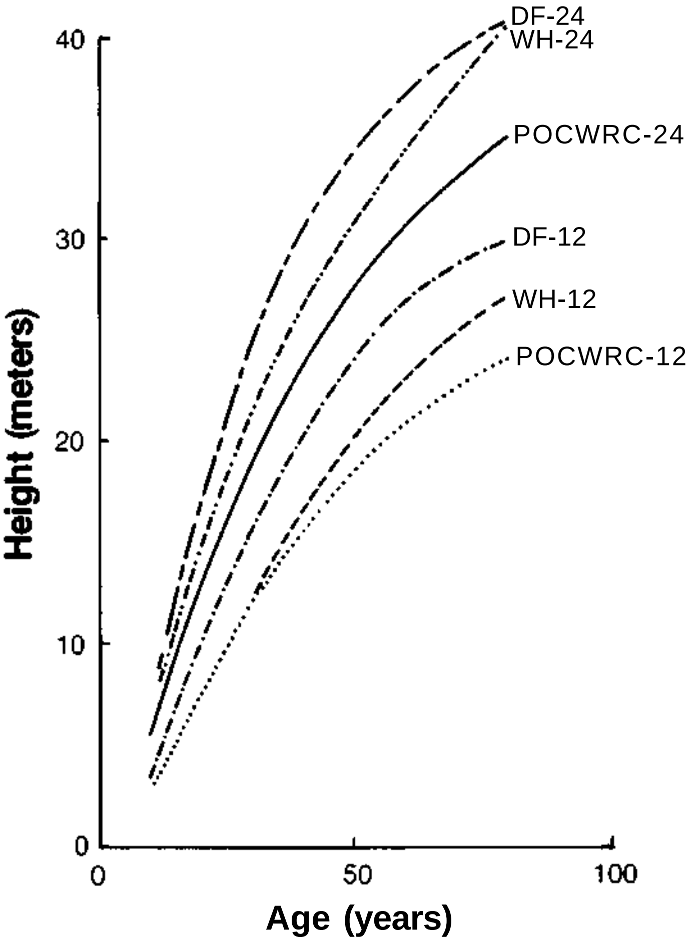

Figure 20.—Height of plantations of Port-Orford-cedar (POC), western redcedar (WRC), western hemlock (WH), and Douglas-fir (DF) for yield classes that produce 12 and 24 m^3/ha in British plantations (Hamilton and Christie 1971).

In pole stands in the northern part of the range, large differences in tree size occur among species; for 53- to 60-year-old trees at one site in coastal Coos County, Douglas-fir was 38 m tall, cedar 28 m (see footnote 10). Height of other young natural stands measured in the northern end of the range was 16 to 22 m at 36 to 44 years and 22 to 23 m at 57 to 61 years (Hayes 1958). Trees in British plantations grow similarly to western redcedar (Hamilton and Christie 1971), but the cedar are considerably shorter than western hemlock or Douglas-fir of the same age (fig. 20). At Bedgebury, England, 29- to 31-year-old stands averaged 8.9 m tall for Port-Orford-cedar compared to 13.5 m for Douglas-fir, 12.8 m for western hemlock, 11.3 m for grand fir, and 7.5 m for western redcedar (Ovington 1953). Ten-year-old Port-Orford-cedar trees growing in Denmark are likewise shorter than are other Oregon conifers on the same 13 sites: mean height for Sitka spruce was 4.4 m; lodgepole pine, 3.9 m; Douglas-fir, 3.8 m; grand fir, 3.0 m; and Port-Orford-cedar, 2.3 m (range 0.8 to 5.0) (Holmsgaard and Bang 1977). Although young trees may grow as much as a meter per year in France, few exceed 35 m at 100 years (Boullard 1974). Height in New Zealand is similar to that in British and European plantations (Streets 1962).

The relationship of height of large, native Port-Orford-cedar trees to age varies with the plant community (figs. 21 and 22; table 52). Trees in the open mixed-pine type on ultramafic soil are relatively tall when young but then height increases slowly after 100 years. The tallest tree measured in Hawk's (1977) vegetation sampling was 69 m (80 cm d.b.h.) in the Coquille Falls Research Natural Area, Coos County. The tallest known cedar, south of Powers, OR, is 73 m.

Elongation of lateral twigs of native understory saplings varies among sites within the same zone and among years; year-to-year patterns can be quite different within the same zone (Zobel 1983) (table 53). During the 1976-1977 drought, growth increased on some shadier sites, but decreased in the open mixed pine forests. Elongation of branches of Port-Orford-cedar in the open at Coos County Forest exceeded growth in the forest, with 159 and 154 mm in 1976 and 1977 (compared to 272 and 250 for nearby Douglas-fir).

Diameter.—Basal diameter of 14-month-old trees in a nursery was 0.30 cm (Liu and others 1975). Growth in diameter of native saplings is greatest in open stands on poor (ultramafic and Blacklock) soils where saplings average a 1.4- to 1.6-mm increase per year at the base of a tree (see footnote 10). Saplings growing in closed forests average 1.0 to 1.2 mm per year. Basal diameter increase in clearcuttings is much faster: 4.6 mm per year on swordfern community sites and 2.9 mm in the mixed fir community. Diameter increments of associated conifer saplings are not significantly different from Port-Orford-cedar within a given community.

An average ring width of ≥3.2 mm is considered fast diameter growth for second-growth trees in Coos County; 1.6 to 3.2 mm per year is moderate (Stillinger 1953).

Young, natural stands in coastal Coos and Curry Counties are 16 to 24 cm d.b.h. at 36 to 44 years, and 28 to 31 cm d.b.h. at 57 to 61 years (Hayes 1958). In one mixed stand where 53- to 60-year-old cedar averaged 47 cm d.b.h., Douglas-fir averaged 73 cm d.b.h. Four coastal plantations 16 and 19 years old, north of the range, averaged 10 to 18 cm d.b.h. (Krygier 1958).

Diameters in thinned plantations in Britain averaged 10 to 14 cm (for the 12- and 24-m^3/ha yield classes, respectively) at age 20, increasing to 32 to 53 cm at age 80. Plantings 29 to 31 years old at Bedgebury averaged 37 cm d.b.h. for Port-Orford-cedar, compared to 52 cm for grand fir, 51 cm for Douglas-fir, 47 cm for western hemlock, and 27 cm for western redcedar (Ovington 1953).

On productive soils in Coos County, unmanaged young Port-Orford-cedar increases in size much less consistently as it ages than does western redcedar (table 54). Although Port-Orford-cedar appears to grow more rapidly early, the basal area increment of western redcedar becomes larger at about 25 years (Imper 1981). Basal area increment of Port-Orford-cedar varied considerably with site; there was a significant increase with higher soil nitrate concentration (coefficient of determination $r^2 = 0.30$). Basal area increment was closely related to tree diameter ($r^2 = 0.74$).

Basal area of Port-Orford-cedar in Hawk's plots ranged from 19 m^2/ha in the mixed pine community to 102 m^2/ha in the beargrass community for stands over 200 years old (see table 19). Because these plots were chosen in well-developed forests, they probably exceed averages over large areas.

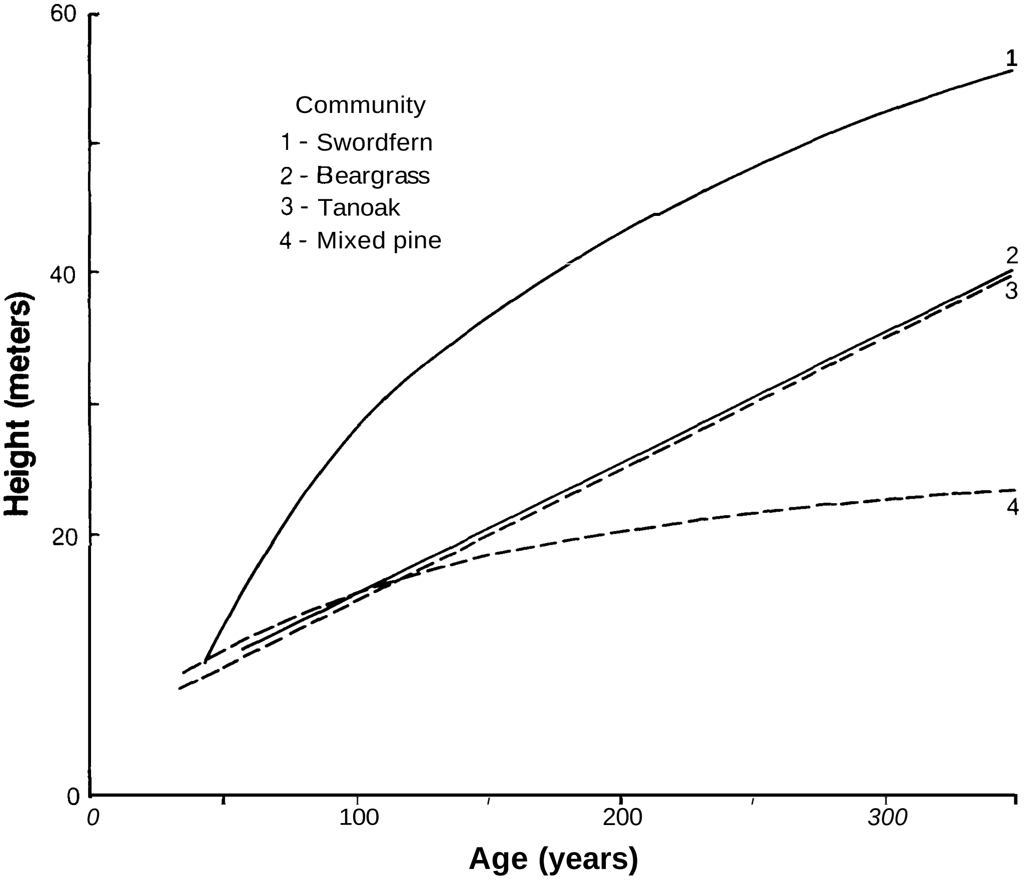

Figure 21.—Height-age relationship of Port-Orford-cedar trees in four low-elevation forest communities. Regression equations for the lines for each community (y = height [meters], x = age [years]) are: swordfern ($n=68$, $r^2=0.48$): $y = -73.8 + 22.1 \ln x$; beargrass ($n=164$, $r^2=0.71$): $y = 6.0 + 0.10x$; tanoak ($n=83$, $r^2=0.53$): $y = 5.1 + 0.10x$; and mixed pine ($n=86$, $r^2=0.46$): $y = -12.9 + 6.2 \ln x$.

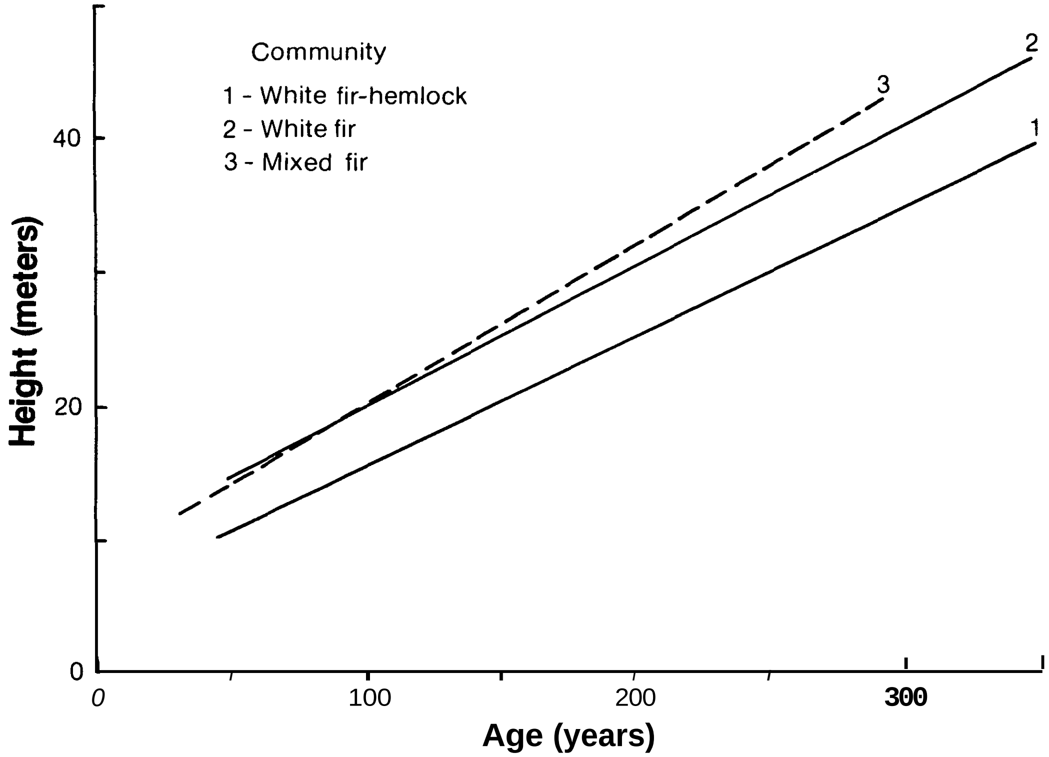

Figure 22.—Height-age relationship for Port-Orford-cedar trees in three communities in the *Abies concolor* zone. Linear regression equations for each community are: white fir-hemlock (n= 136, r^2=0.45): y = 5.7 + 0.10x; white fir (n=98, r^2=0.36): y = 9.7 + 0.10x; mixed fir (n=71, r^2=0.48): y = 8.4 + 0.12x.

Table 52—Height of Port-Orford-cedar trees, 1, 2, and 3 centuries old (±10 years), major old-growth forest communities

(In meters)

	Age (years)		
Community	100 ± 10	200 ± 10	300 ± 10
Swordfern	30	47	63
Rhododendron	--	45	53
Beargrass	13	25	31
Tanoak	12	29	44
Mixed pine	18	21	29
White fir-hemlock	12	26	41
White fir	13	25	46
Mixed fir	12	36	50

-- = insufficient data available.

Source: Hawk 1977.

Table 53—Elongation of lateral twigs of native saplings, by community and site, for 3 years

Community	Site 1/	1975	1976	1977	Difference 1976-1977
		- - - Millimeters - - -			
Swordfern	Remote	52	54	40	NS
	Coquille River Falls	32	43	53	*
Tanoak	Agness	23	37	32	NS
	Pine Point	28	41	41	NS
	Orleans	37	48	42	NS
Mixed pine	Agness	--	32	16	**
	Pine Point	38	72	51	**
	Kerby	29	29	26	*
White fir	Game Lake	19	49	56	*
	Castle Lake	--	26	28	NS
Mixed fir	Grayback	37	52	64	*

** = significantly different at 0.01; * = significant at 0.05 level; NS = not significant; -- = no data.

1/ Site locations shown in figure 5.

Sources: Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis; Zobel 1983.

Table 54—Correlation of height, diameter, and 10-year basal area increment with age, Port-Orford-cedar and western redcedar, and the predicted values for an age of 50 years, for unmanaged stands on productive soils in Coos County, OR[1]

Item	Port-Orford-cedar	Western redcedar
	- - - Correlation coefficient - - -	
Correlation of age with:		
Height	0.38	0.66
D.b.h.	.36	.76
Basal area increment	.27	.60
Predicted value, 50 years:		
Height (meters)	15.4	14.9
D.b.h. (centimeters)	18	19
10-year basal area increment (square centimeters) at 50 years	*36*	65

Source: Imper 1981.

Throughout much of their life, cedars grow more slowly in diameter than Douglas-fir; however, in trees older than about 300 years, growth rate of cedar declines less than does that of Douglas-fir (fig. 23). The ratio for wood basal area of Douglas-fir to Port-Orford-cedar declines from 3.1 at 100 years to 1.2 at 400 years.

Diameter reached by old trees and the relationship to height vary considerably among forest communities. Old-growth trees on ultramafic materials do not grow as large (table 55) and are shorter for their diameter (for example, fig. 24) than are those on most other soils.

Port-Orford-cedar occasionally reaches 1 m d.b.h.; Hawk (1977) encountered 28 such trees from 220 to over 560 years old. Of these, 7 were less than 300 years old, 12 were 300 to 350 years old, 5 were 350 to 400 years old, and 4 were over 400 years.

The largest known Port-Orford-cedar, south of Powers, OR, was 67 m tall, 1146 cm in circumference (equivalent to a diameter of 3.65 m), and had a crown spread of 12 m in 1972 (American Forestry Association 1978). In 1981 a sign at the tree gave height as 73 m, diameter as 3.78 m, and volume as 255 m^3.

Volume and yield.—Estimates of volume growth are few. Port-Orford-cedar in young stands in coastal Oregon (see table 32) produce a mean annual increment of 5.1 to 11.5 m^3/ha at 36 to 44 years and 13.7 to 16.9 m^3/ha in older stands. Production in young European plantations and better ones in New Zealand is somewhat similar (tables 56 and 57).

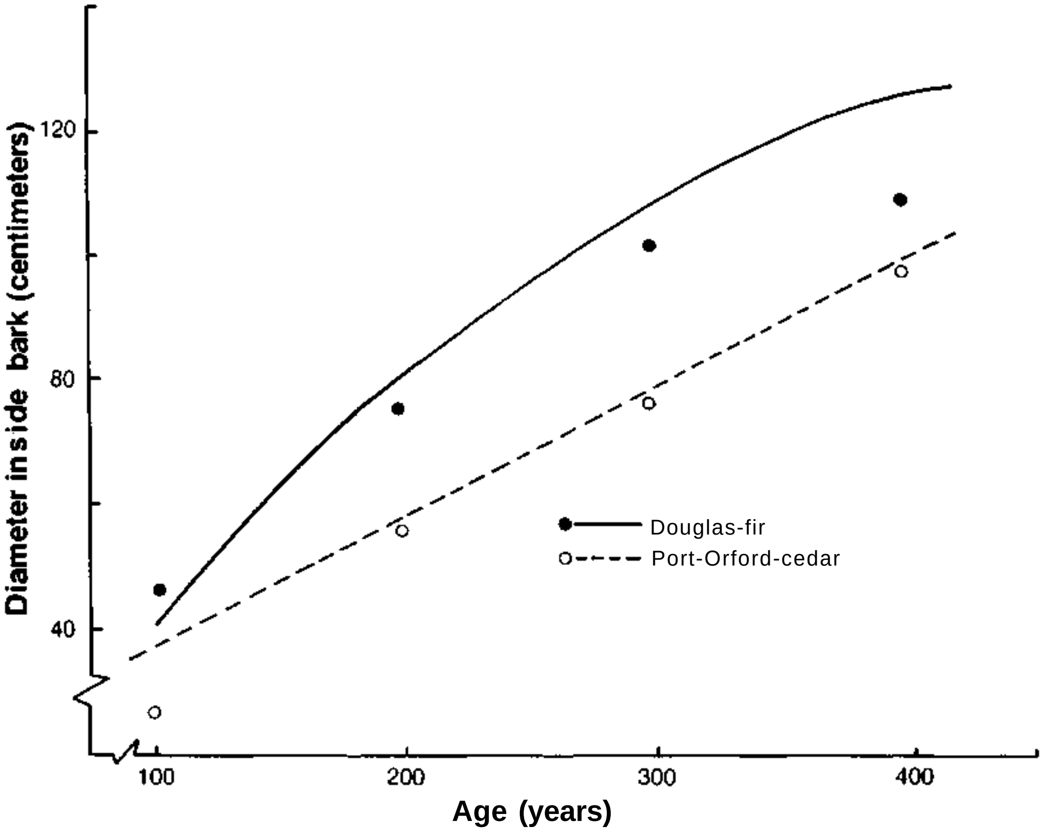

Figure 23.—Change of diameter inside bark with age for native Port-Orford-cedar and Douglas-fir. Regression lines are constructed from diameters and ages of 67 and 23 stumps, respectively, from the same group of sites throughout the range; R^2 values for the regressions are 0.65 and 0.47, respectively. Plotted points are average inside-bark stump diameters at 100, 200, 300, and 400 years for all stumps reaching a given age; numbers decline from 56 Port-Orford-cedar and 23 Douglas-fir at 100 years to 4 and 7 trees, respectively, at 400 years. (Unpublished data on file at Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

Table 55—Diameter of a tree of mean basal area in forests 200 years or older for eight major forest communities

(In centimeters)

	Community							
Forest community	Swordfern	Rhododendron	Beargrass	Tanoak	Mixed pine	White fir-hemlock	White fir	Mixed fir
Port-Orford-cedar	86	66	51	63	43	51	45	68
Douglas-fir	95	137	65	96	48	84	50	58
Western 'hemlock	26	32	33	--	--	36	--	--
Pines	--	--	38	71	21	--	76	62
White and Shasta red fir	--	--	--	--	--	26	99	54
Other conifers	46	54	--	--	38	38	30	45
Hardwoods	29	--	51	35	--	22	--	18
Primary substrate is ultramafic	-	-	+	+	+	-	+	

-- = absent; - = no; + = yes.

Source: Hawk 1977.

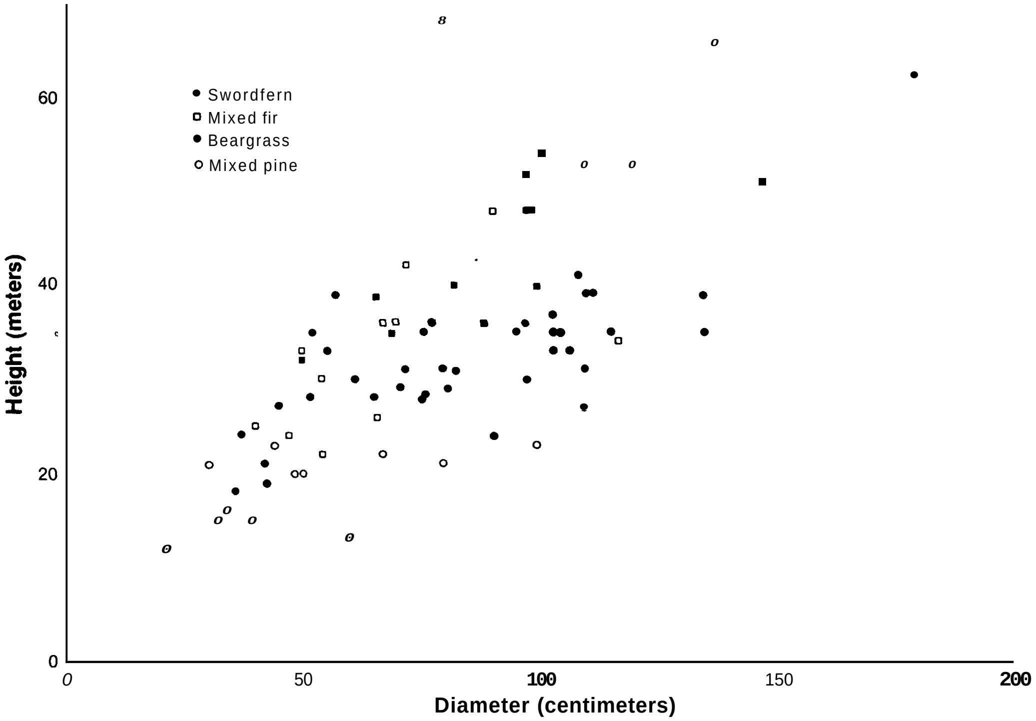

Figure 24.—Relationship of height and diameter of trees over 200 years old in four forest communities. Beargrass and mixed pine communities grow on ultramafic substrates. (Unpublished data on file, Department of Botany and Plant Pathology, Oregon State University, Corvallis.)

Table 56—Yield per hectare of Port-Orford-cedar in young plantations, Europe and New Zealand

Location	Stand age	Stems	Basal area	Average diameter	Average height	Volume	Mean annual increment
	Years	Number	Square meters	Centimeters	Meters	--- Cubic meters	----
Belle-Etoile, Belgium	20	2978	28	11	8	98	4.9
Belle-Etoile, Belgium	30	2637	46	15	13	275	9.2
Westland, New Zealand	28	988	--	22	13	223	7.9
Holstenshuus Forest District, Denmark:							
Living trees	28	2126	34	14	13	273	12.8
Removed in thinning	--	1657	14	--	--	84	
Living trees	46	1301	50	22	17	471	13.4
Removed in thinning	--	1284	20	--	--	144	
Vernand-Dessons, Switzerland 1/	45	840	--	24	22	527	11.7

-- - no data.

1/ Planted in mixture with beech and spruce. Some cutting mentioned. Included only about half the number of cedar stems desired for pure stands on good sites.

Sources: Hayes 1958, Streets 1962.

Table 57—Yield per hectare of Port-Orford-cedar in young plantations, New Zealand

Location 1/	Stand age	Basal area	Average height	Volume	Mean annual increment
	Years	Square meters	Meters	- - - Cubic meters	- - -
Flagstaff	38	83.1	13.4	484.8	12.8
Hamner	45	53.0	20.4	447.5	9.9
Port Chalmers	45	106.1	17.7	678.0	15.1
Ross Creek	47	108.1	23.5	927.7	19.7
Mahinapua	47	88.1	22.1	756.5	16.1
Golden Downs	48	40.1	20.2	280.1	5.8
Golden Downs	48	36.9	20.4	270.5	5.6
Karioi	51	29.3	22.3	237.0	4.7
Karioi	51	69.3	21.6	532.5	10.4
Karioi	51	8.2	12.8	11.6	.2
Karioi	51	13.3	18.7	86.7	1.7
Karioi	51	18.7	16.6	89.6	1.8
West Tapanui	66	60.3	23.7	512.5	7.8
Raincliff	78	82.2	35.1	1003.8	12.9

1/ All except Karioi are on the South Island.

Source: Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua.

Table 58—Attributes of British plantations of Port-Orford-cedar and western redcedar for the least and most productive yield classes (supporting maximum mean annual increment of 12 and 24 m³/ha)[1]

Age	Density		Height		Diameter		Basal area maintained after thinning		Cumulative yield	
	12	24	12	24	12	24	12	24	12	24
years	trees/ha[2]		meters		centimeters		- - m²/ha - -		- - m³/ha - -	
20	3575	2186	8	13	10	14	28	35	50	232
40	1730	746	16	24	18	30	42	54	377	901
60	984	451	21	30	26	43	51	66	706	1439
80	738	347	24	35	32	53	59	76	953	1838

[1] Yields include thinnings and are computed for top diameter of 7 cm outside bark.

[2] 1 tree/ha = 0.405 tree/acre.

Source: Hamilton and Christie 1971.

Estimated yields in British plantations for Port-Orford-cedar and western redcedar (considered as a unit) range from 12 to 24 m³/ha at the peak of mean annual increment (Hamilton and Christie 1971) (table 58); this is within and higher than the ranges for young stands cited above. The peak value of mean annual increment was first reached at 55 to 70 years. The pattern of current annual increment differed from Douglas-fir and western hemlock and with the productivity of the site (fig. 25). Growth of Douglas-fir, as noted above for the natural range, is earlier. Compared to Douglas-fir, cedar plantations (table 58) are 2 to 3 times denser with 1.4 to 1.5 times as much basal area for the same quality of site. Yields in French plantations also do not rival those of Douglas-fir or grand fir (Boullard 1974).

The higher yields in Britain (compare table 58 to tables 31, 56, and 57) probably result from inclusion of thinnings, the small top diameter, and the use of pure stands. The older natural stands were also much more dense and had more basal area than those used in Britain.

The overall volume growth figures for Coos County (table 59), indicate average annual increment of 5.9 m³/ha, which is 3.6 percent of the growing stock; saw timber growth is less—2.0 to 3.1 percent of the growing stock. Growth in more southern locations is slower at 1.4 to 2.4 m³/ha and about 1 percent of the growing stock for both cubic and board-foot volume.

Volumes present in old-growth forests are given in Chapter 4, primarily in tables 27 and 28. Based on recent cruises, mean volumes of 280 m³/ha still occur over areas the size of a clearcut in the best part of the range of Port-Orford-cedar. Single acres have yielded up to 1400 m³/ha (Gibson 1913) (see table 28). Some early estimates of volume and relative importance of Port-Orford-cedar in coastal Coos County appear to have been excessive. For example, Gibson (1913) reports an average of 210 m³/ha over 103 600 ha. Sargent (1881) estimated 18 193 m³/ha in an area 12 by 20 miles, certainly a misprint, which was not repeated in his later reports (1884, 1896).

Apparently only one volume table has been produced for Port-Orford-cedar (fig: 26):

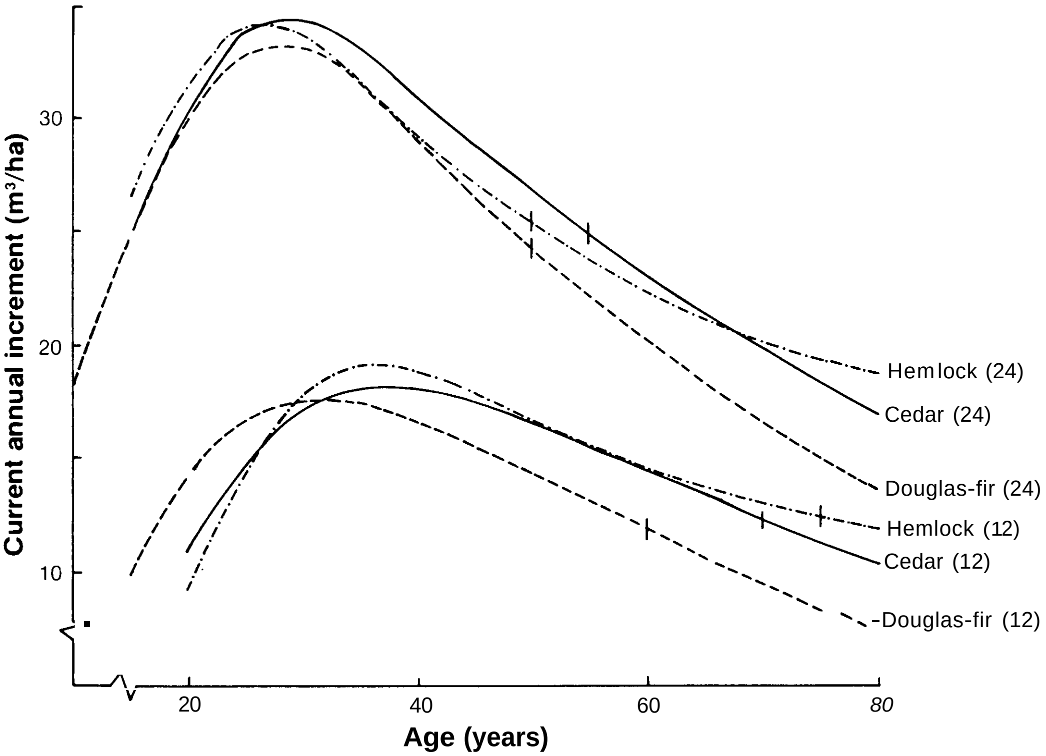

Figure 25.—Time course of current annual volume increment for Port-Orford-cedar and western redcedar (considered together), Douglas-fir, and western hemlock in plantations in Great Britain for good and poor sites (capable of producing a peak mean annual increment of 24 and 12 m³/ha, respectively). The vertical line indicates the time when the peak mean annual increment is reached (from data of Hamilton and Christie 1971).

Table 59—Timberland area, cubic volume, and net annual growth of Port-Orford-cedar on unreserved timberland in three counties in Oregon and three counties in California

Location	Area	Volume		Net annual growth 1/
	thousand ha	thousand m^3		thousand bd. ft.
Oregon:				
coos co.	17.8	2,910	105.8	13,436
Curry Co.	7.7	2/ 255	2/ 7.3	2/ 760
Josephine Co.	1.6	198	2.3	250
California:				
Interior counties 3/	2.4	538	5.7	1,100

1/ International 1/4-inch rule.

2/ Does not include volume or growth on National Forest timberland.

3/ Shasta, Siskiyou, and Trinity Counties, northern California.

Source: Bolsinger 1976; personal communication, 1980, T. O. Farrenkopf, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Species . . . . PORT-ORFORD-CEDAR *(Chamaeocyparis lawsoniana)*
Unit of measure . . . . . . *Board-foot*
Variables . . . . *D.b.h.* and *number of 16-foot* logs
Log rule . . . . Scribner
Scaling length for logs . . . *16 feet*
Slump height . . . . 1 5 lo 4.5 feef
Top d i.b . . . . 8 lo 15 inches
Trim alowance per log . , . *0.3 feet*
Method. . . . . *Frustum* form *factor*
Number of trees 58
Location of trees . . . . . . Coos Bay *Region of* Southwesfern Oregon
Accuracy. . . . . Aggregafe deviation 1.85 percent high
Author . . . . E J. Hanzlik, U.S.Forest Service. Pacific Northwest Region
Source . . . . Fiie *report*
Year *1934*

D.b.h.	Volume in tens of board-feet when number of 16-foot logs is —										
(inches)	2	3	4	5	6	7	8	8	10	11	12
12	9	14	18								
14	10	15	20	27							
16	11	17	23	31							
18	12	19	27	37	44						
20	13	22	31	42	51	60					
22		25	36	49	60	70					
24		29	41	55	68	81					
26		33	47	63	78	92					
28		37	53	70	87	103	123				
30		41	60	78	97	117	139				
32		45	67	87	108	130	154				
34		50	74	98	120	144	170				
36		55	81	106	132	158	185	215			
38			88	115	145	173	201	232			
40			95	126	158	187	218	248			
42			102	137	171	201	235	267			
44				147	184	217	252	286	381		
46				157	197	235	270	307	344	386	
48				167	210	252	288	330	370	416	
50				178	223	268	308	353	396	444	
52					236	285	328	378	423	472	
54					249	303	348	403	450	502	
56					262	318	370	425	476	531	582
58					275	336	390	450	503	560	616
60					288	353	412	473	530	590	648
62						370	432	496	556	618	682
64						388	452	520	582	650	716
66						404	472	542	609	679	751
68						422	493	566	635	708	782
70						439	514	588	663	736	815
72						455	534	612	689	766	848
74						472	554	635	716	795	882
76						489	575	660	742	824	914
78						506	596	682	770	853	938
80						523	616	705	796	882	980

Figure 26.—Volume table for Port-Orford-cedar (Johnson **1955).**

Reproduction

Vegetative reproduction.—Reproduction of Port-Orford-cedar by layering occurs in sand dunes (Egler 1934, Hawk 1977), in some high-elevation forests, and in plantations (Iacovlev 1955), but the importance of layering seems to be small and localized. Production of adventitious roots allows the cedar to survive burial by sand (Cooper 1958, Egler 1934). On Blacklock soil near Coos Bay, branches of windthrown trees have developed into vigorous trunks with fuller crowns, better color, and apparently much faster growth than have trees from seedling regeneration (see footnote 10).

Rooting of cuttings, extremely important for horticulture, is relatively easy (Doran 1957, Larsen and Guse 1975, Welch 1966). Some cultivars, however, root much less easily than others (for example, 'Kelleris' with 58 to 78 percent of cuttings rooted vs. 'Triomf van Boskoop' with 0 to 11 percent) (Osterbye and Eriksen 1971). Cuttings with primary leaves root more easily than those with mature foliage (Masters 1896). One cultivar that is easy to root ('Fletcheri') has a low content of growth inhibitor and contains a substance that stimulates rooting of mung bean (Tognoni and Lorenzi 1972).

Cuttings may be taken in autumn or winter, although Bean (1950) suggests late summer. Some cuttings root better with hormone treatment (Tognini 1972); others root well without treatment. For western Oregon, cuttings should be taken from the terminal parts of branches, low in the crown (younger trees root better), after chilling has been completed and before growth resumes (that is, December to February).[19]

Cultivars vary in their response to hormone treatment, to misting vs. a plastic cover (Osterbye and Eriksen 1971), and to the effects of spacing (Kelly 1977). Wide spacing seems more important for those less easy to root. Wide spacing (30-45 cm^2 of bed per cutting) gives a higher percent of rooting and less disease damage, and the number of rooted cuttings produced is about the same. Root quality, fibrousness, and length of the cultivar 'Ellwoodii' increased considerably as rooting compost temperature rose from 15 to 20 °C, but increased only slightly from 20 to 25 °C (Whalley and Randall 1976). Port-Orford-cedar (cultivar 'Allumi') has been grafted to *Phytophthora*-resistant root stocks of other Cupressaceae, although success varied (Torgeson and others 1954).

Flowering — Sexual organs of Port-Orford-cedar are not segregated by crown position, as they tend to be on Pinaceae, but are borne on the same branches (Erspamer 1953, Rouane 1973). The indeterminate vegetative apex of small branches changes to a determinate reproductive apex whose growth ceases after cone formation. The transformation from vegetative apex to both types of reproductive apex begins after the production of a relatively uniform number of leaf pairs during a given season; however, the apices on the youngest, fastest growing branches produce seed cones, and the slower growing ones produce pollen cones (Rouane 1973). This results in a consistent pattern of distribution of the sexes on the branches (fig. 27).

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[19] Personal communication, 1980, A.N. Roberts, Oregon State University, Corvallis.

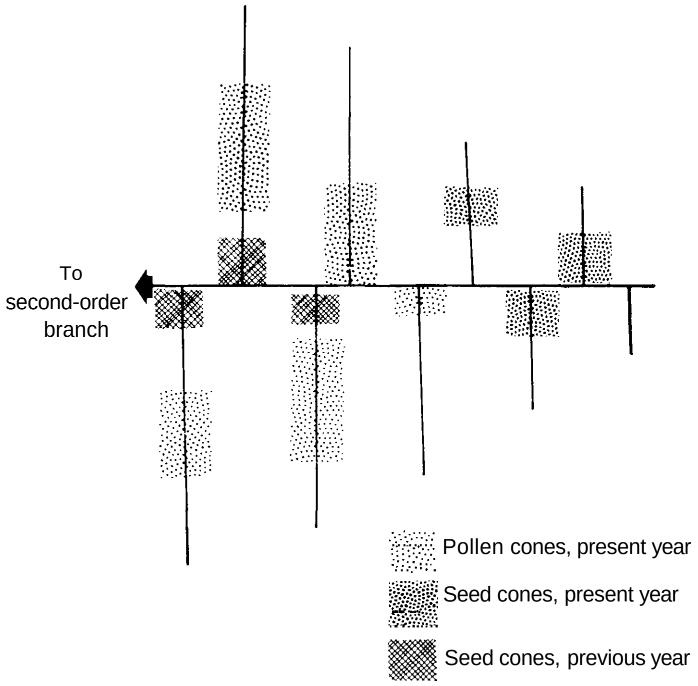

Figure 27.—A schematic diagram of the distribution of male and female reproductive organs on Port-Orford-cedar. The horizontal line represents the youngest part of the axis of a third-order branch, apex to the right. The vertical lines represent fourth-order branches. The zones along the fourth-order axes where branch systems with the two types of cones are inserted are shown. The female cones are actually borne on sixth-order branchlets, and the male strobili on the sixth and seventh orders. (Based on Rouane 1973, figs. 38 and 39, used courtesy Laboratoire Forestier de Toulouse.)

Reproductive primordia are formed in the late spring or summer. The initiation of pollen-cone primordia is well advanced by mid-June (probably beginning in mid-May) in Berkeley, CA, south of the native range (Erspamer **1953).** The young pollen cones become visible in July, and initiation of sporophylls continues into August, with 10-12 pairs being produced. Sporogenous tissue is apparent in pollen cones in early July; its divisions continue into December. Male sporogenesis then begins and continues through February, with pollen shed in early March in Berkeley. In Japan, flower bud formation is in June and pollen formation is later, with meiosis in early March and mature pollen in early April (Hashizume **1973).** Gianordoli **(1962)** records even later development: meiosis in early April and pollination in late April. There is little information from the natural range. In coastal Coos County, pollen shed has been noted as early as mid-March (see footnote 10), and at the southern end of the range in montane Humboldt County, CA, in late March and early April of one year (see footnote **11).**

Pollen of Port-Orford-cedar is yellow to reddish, has no bladders, is half to three-quarters spherical, and has a granular surface. It has the lowest falling velocity of 33 tree species measured (Eisenhut 1961, Ho and Sziklai 1973). Diameters of the pollen are given as: 24 to 36 by 21 to 35 μ (mean 32 x 24) (Axelrod and Ting 1961); 26 to 31 μ (Eisenhut 1961); 32 to 38 μ (Camus 1914); and 26 to 43 μ (mean 36) (Hyde and Adams 1958). Pollen is larger than that of Alaska-cedar (Axelrod and Ting 1961). Optimum conditions for germinating pollen of several Cupressaceae (including Port-Orford-cedar) are a 2- to 5-percent solution of sucrose in distilled water, temperature of 26 °C, and high humidity (Razmologov 1964).

Seed cones represent a leafy shoot system with a reduced vascular system (Lemoine-Sebastian 1972), and the bract and scale fused. The number of ovules per scale varies, and some scales toward the apex are sterile (Aase 1915). No specific information about the time of initiation of seed cones seems to be available. Ovules were formed in August (Hashizume 1973); meiosis had begun early the following March in one study (Cecchi Fiordi and Maugini 1977) and by mid-April in another (Gianordoli 1962). Development is not synchronous among ovules in the same cone (Cecchi Fiordi and Maugini 1977, Gianordoli 1962). Pollination occurs a week or two after megaspore meiosis; fertilization follows in somewhat over a month (Gianordoli 1962). Pollination drops are present (Cecchi Fiordi and Maugini 1977, Gianordoli 1962). Seeds mature in the September or October following pollination.

Cecchi Fiordi and Maugini (1977) noted considerable degeneration of megaspores, which would reduce the percentage of seeds that were viable. Anatomical and cytological details of reproduction are described by Bonnet-Masimbert (1971), Cecchi Fiordi and Maugini (1977), Chesnoy (1973), Erspamer (1953), Gianordoli (1962), Hashizume (1973), and Lemoine-Sebastian (1970).

Initiation and sex of flower buds of Port-Orford-cedar can be controlled by adding hormones, specifically gibberellins (Bonnet-Masimbert 1971, Hashizume 1973). A single spray of gibberellic acid (50 mg/1) on the foliage induced flowering in plants less than 1 year old (Bonnet-Masimbert 1971). Ethrel enhanced the effect, but benzyladenine did not increase flowering (table 60). Photoperiod modifies flowering (tables 60 and 61). A long-day—>short day—>long-day regime after treatment is necessary for effective flower production. At least 2 weeks of long days are necessary to produce female flowers, and without the 2 weeks of short days following, pollen will not mature. The final long days are necessary for seed cones to mature and seeds to develop. Induced pollen cones may revert to vegetative growth in long days. Hashizume (1973) found treatment of 3- to 7-year-old trees with 50 to 200 p/m of gibberellic acid effective in inducing flowering when sprayed 3 to 5 times during June to August; 50 p/m was as effective or more so than higher concentrations. Treatment with gibberellins can reverse the sex of developing male flowers; ovules may form in the axils of the male sporangia, or male organs may differentiate into ovules (although no cones develop in the latter case) (Hashizume 1973). Such bisexual cones have also been found on untreated trees (Masters 1891).

Table 60—Influence of various growth substances on flowering of 9-month-old Port-Orford-cedar

	Long day---> Short day		Long day---> Short day---> Long day	
Treatment 1/	Male	Female	Male	Female
	Percent flowering 2/			
"Tween 80"	0	0	0	0
+ GA	100	60	100	60
+ GA + E	100	80	100	100
+ GA + BA	100	20	100	80
+ GA + BA + E	100	80	100	80
+ BA + E	0	0	0	0

1/ GA = gibberellic acid (100 milligrams per liter (mg/l)); BA = benzyladenine (10 mg/l); E = Ethrel (200 mg/l); "Tween 80" is a wetting agent.

2/ Of five plants.

Source: Bonnet-Masimbert 1971.

Table 61—Effect of photoperiod on the induction of flowering of 9-month-old Port-Orford-cedar by spraying with a solution of gibberellic acid (100 mg/l), benzyladenine (10 mg/l), and Ethrel (200 mg/l)

	Male flowering		Female flowering	
Photoperiodic sequence	Percent of plants 1/	Intensity 2/	Percent of plants 1/	Intensity 2/
LD 3/	100	+	0	
SD 4/	90	++	0	
1 week LD---> SD	100	+++	0	
2 weeks LD---> SD	100	+++	20	+
3 weeks LD---> SD	100	++++	20	++
4 weeks LD---> SD	100	+++++	40	++
1 week LD---> 4 weeks SD---> LD	100	++	0	

1/ of ten plants.

2/ + = few pollen or seed cones; +++++ = many pollen or seed cones.

3/ LD = 16-hour days.

4/ SD = 10-hour days.

Source: Bonnet-Masimbert 1971.

Seed production and germination.—Open-grown container seedlings produce cones 3-4 years after planting. Most reports indicate that seed production begins early at 5 years (Macdonald and others 1957) to 9 years, becoming general by 20 years and continuing into old age (Hayes 1958, Zobel 1979). Flowering, with subsequent seed development, may be induced by gibberellin treatment of plants as young as 7 months (see section on flowering).

Seeds of Port-Orford-cedar are small, about 3-4 mm long, and weigh about 2 mg each (range, 0.76 to 5.7 mg; 175,000 to 1.3 million per kg) (Debezac 1964, den Ouden and Boom 1965, Harris 1974). Seeds are intermediate in size for the genus. The seed wall includes several resin-filled secretory pockets (Camus 1914). Seeds ripen in September or October, but are dispersed throughout the year, with peaks in autumn and smaller peaks from winter to spring (fig. 28). Roughly 50 to 60 percent fall by mid-January and 85 to 90 percent or more by May 1 (Hayes 1958, Zobel 1979). Seed production is less variable from year to year and there is less regional synchronization of seed crops than is characteristic of Pinaceae. No site produces a large crop 2 years in succession (Zobel 1979), but good seed crops occur at intervals of 3 years in Great Britain (Macdonald and others 1957) and 4-5 years in natural forests (Hayes 1958, Zobel 1979). Seldom does there seem to be a crop failure.

Cones yield about 20 percent of their weight in seeds (Harris 1974). Seed production ranged from 20,000 per ha to 4.6 million per ha in 30 seed crops; the average was lowest in the mixed evergreen zone (Zobel 1979, table 62). Seed production per unit of basal area was less variable among zones (table 62), with a productive seed year recorded from young (65 years old) and old-growth stands and from good and poor sites in all vegetation zones. Of 30 seed crops sampled, five exceeded 100,000/m^2 of basal area; six produced 20,000 to 60,000; six were 10,000 to 20,000; and 13 produced less than 10,000/m^2 basal area (but there were no crop failures) (Zobel 1979). There was some evidence that open-grown trees produce more seed than those in denser stands at the same site.

Seed are apparently not dispersed very far by wind (Camus 1914, Hayes 1958, Sudworth 1908); one to three tree heights seem the usual distance of invasion into clearcuttings, although this is highly variable. The small wings aid flotation in water, and water-dispersal may be of some importance in the streamside habitats the species often occupies.

Seed should not be dewinged and should be stored frozen and sealed with moisture below 10 percent (Harris 1974). In one case, viability of seed stored this way dropped from 56 to 43 percent in 7 years, while the viability of seed stored at room temperature was lost completely. Storage up to 16 years is possible (with 13 percent germination) (Schubert 1954).

Germination can be poor; it ranged from 11 to 44 percent for seed from seed traps at seven sites in 1975-76 (Zobel 1979). Germination was best for seeds released during periods of heavy seedfall, but was not correlated with differences in seed production among sites. Other seed collections germinated at about 50 percent or better (den Ouden and Boom 1965, Harris 1974).

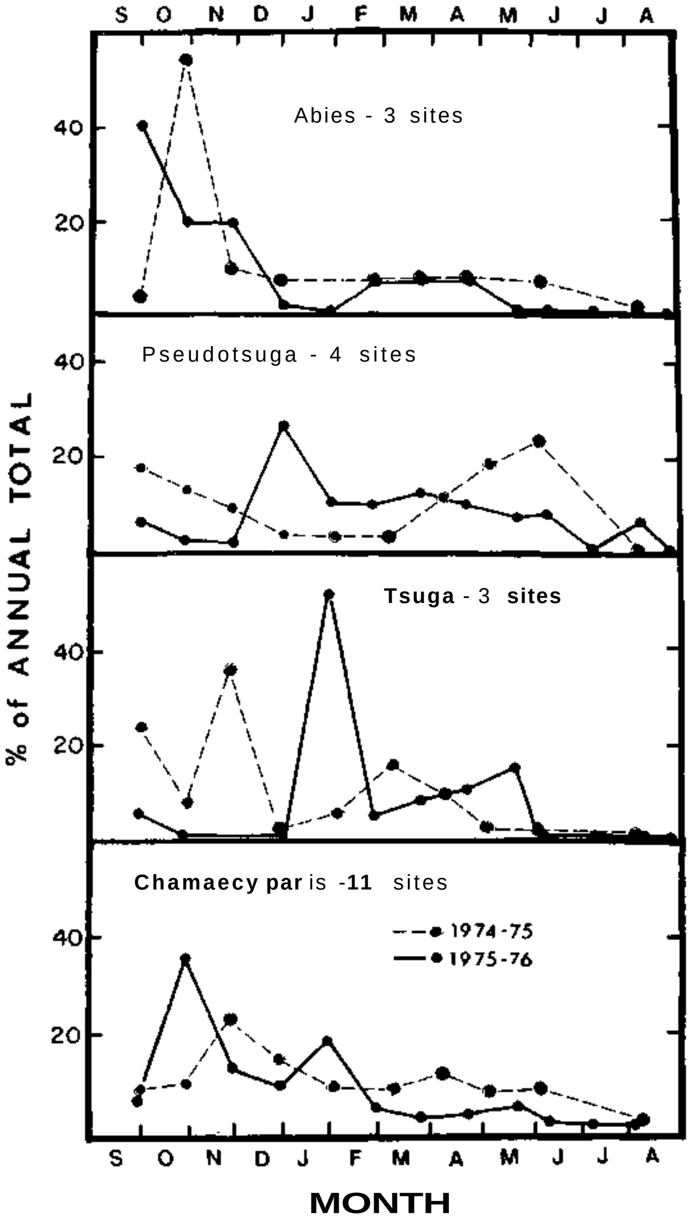

Figure 28.—Average percentage of total annual seedfall in 2 years for Port-Orford-cedar in 12 natural forests and for 3 associated Pinaceae (from Zobel 1979, used courtesy National Research Council of Canada).

Table 62—Mean annual seed production for 3 years, expressed as seeds per hectare and per unit of cedar basal area, Port-Orford-cedar in natural forests

Vegetation zone	Number of seed crops sampled	Seed production 1/	
		Per hectare	Per square meter of basal area
		- - - - - - - Thousand seeds	- - - - - - - - -
Picea sitchensis + *Tsuga heterophylla* 2/	9	965 (72-4622)	32.3 (5.0-182.7)
Mixed evergreen	10	426 (20-1594)	48.4 (0.6-184.9)
Abies concolor	11	1071 (41-4511)	38.4 (1.3-154.9)
All samples	30	829	40.2

1/ The range is shown in parentheses.

2/ Previous reports for the *Tsuga heterophylla* zone were 1.5 and 3.1 million per hectare.

Source: Zobel 1979.

Stratification seems not to be required for reasonable germination in most cases (Harris 1974) but may give slightly larger seedlings (Forestry Commission 1967). Germination is accelerated by red light (to 56 percent at 13 days compared to 32 percent at 27 days for the control) and retarded by far-red light (to 20 percent at 32 days) (Panasyuk and Vasileiko 1973). Indole acetic acid increases germination somewhat at 0.01 to 9.9 mg/1, and reduces it at higher concentrations; 2,4,5-T reduced germination at all concentrations tested (Fromantin 1958a, 1958b).

In a Taiwanese nursery, germination required an average of 16.4 days (range of 8 to 26) after planting, the longest of five ***Chamaecyparis*** species tested (Liu and others 1975). A similar time is required for seeds germinated in the laboratory at 17-20 °C. Most germination of seed planted under an intact native forest was in early to mid-June; 9 percent occurred from mid-June to mid-July; and 2 percent was later (Zobel 1980). In Washington, Port-Orford-cedar germinated in the third and fourth seasons after sowing (0.5 percent each year compared to 1 percent the first year), the only conifer in the test to do so (Isaac 1940). No sign of significant delayed germination occurs, in more extensive seeding trials (Zobel 1980).

Compared with its usual associated conifers, Port-Orford-cedar is intermediate in age of first reproduction; is intermediate in earliness of seed release; has large seed crops but moderately small seeds; has moderate seed longevity; and has a low stratification requirement (Minore 1979). It produces more seed (relative to its basal area) than do Douglas-fir and white fir on the same sites but fewer than western hemlock. There is much less difference among these species when production of seed mass is considered (Zobel 1979). Seedfall of cedar is generally distributed more evenly over the year than that of associated Pinaceae (see fig. 26). Considerably fewer seeds of Port-Orford-cedar fall per hectare than are reported for Asian ***Chamaecyparis*** and for ***C. thyoides.***

Seedling establishment.—Seedlings produce two cotyledons, then two primary leaves at right angles to the cotyledons, and then whorls of four primary leaves each. Cotyledons were 0.62 cm long (range 0.3 to 1.0 cm) by 0.1 cm wide and were the longest and narrowest of the species tested by Liu and others (1975). Camus (1914) gives 0.8-1.2 cm as the length. Port-Orford-cedar required 183 days (range 148 to 229) before secondary leaves appeared and produced 46 primary leaves (range 36 to 64) (Liu and others 1975).

Although seedling establishment can occur on natural forest floor, some soil disturbance greatly accelerates it. Germination, establishment, and seedling growth in natural forest understory are better on spaded plots than on those with litter removed, burned, or left intact (Zobel 1980). No seedlings survived the second season on plots with the litter removed or burned. By the end of the third season, an average of 5 percent of the original germinants were alive on the spaded plots and 6 percent on intact litter. None survived, however, under a young, dense forest where initial seedling establishment had been most successful.

Seedling establishment after clearcutting in the northern end of the range is adequate within a reasonable distance of a seed source. James and Hayes (1954) recommend that clearcut units be **less** than 200 m across; alternatively, shelterwoods with considerable remaining cedar can be used if natural seedlings are relied on for regeneration. Cedar establishment was limited by dense ground cover, but James and Hayes (1954) found no significant effect from other site conditions they measured. Cedar was generally more prevalent in regeneration than in the original stand. Recent observations throughout the range confirm the results of James and Hayes for most areas. Effective natural regeneration occurs within about 80 to 110 meters of a seed source in most recent clearcuttings. The species appears to reproduce itself at least in proportion to its original importance. In the southern coastal area, the cedar is establishing higher on the slopes than it did in the original stand. Silviculturists generally consider Port-Orford-cedar to be a dependable reproducer close to a seed source, although one report describes its exclusion by Douglas-fir (American Lumberman 1911).

Establishment in natural forests appears to have occurred, at least to some extent, in waves following disturbance (Hawk 1977, Viers 1982), probably fires. There are several size classes of Port-Orford-cedar in some forests in which both fire-intolerant and shade-intolerant species have only one size class; this suggests that cedar regeneration continues beneath the forest canopy. Often the largest cedars have multiple fire scars.

Data from Hawk's (1977) sampling were used to try to relate the amount of reproduction of Port-Orford-cedar in natural forests to site and stand variables. There were significantly fewer seedlings and saplings, and they had less cover on steeper slopes, on sedimentary rock types, and on soils developed on alluvium, than in other conditions. Use of these variables accounted for only about 15 percent of the variability in numbers and cover of reproduction.

In American nursery practice (Harris 1974), the seed is sown in spring at 322 to 538/m² and covered by 0.3 to 0.6 cm soil. Stratification of seed and shading until midseason are recommended. Bare-root seedlings were grown as 1-1 or 2-0 seedlings in the United States (Harris 1974, Ruth 1957). Container-grown stock 1 season old and 20-30 cm tall has recently been used successfully.

British practice (Macdonald and others 1957) involves broadcasting seeds at 13.5 g/m². Seedlings were lifted after the first year in heathland nurseries or after the second year in others; in some cases 2-1 plants have been used (Harris 1974). Three-year-old seedlings were planted in New Zealand (Streets 1962) and even older ones have been recommended (Schenck 1907). No special nursery practices are necessary for the species.

Seedlings may be stored successfully during the period March to July; 2 °C is a more favorable storage temperature than – 2 °C (Aldhous and Atterson 1963). In Oregon, seedlings planted after 2 months in cold storage grew and survived as well for the first 10 years as those planted without storage (Ruth 1957); seedlings planted in November survived better than those planted in April (Krygier 1958).

Port-Orford-cedar is cheap to grow and easy to move and establish in Great Britain (Ackers 1947). In Denmark, first-year survival in 13 plantations was 91 percent—among the best of the western North American conifers used. Establishment and maintenance expenses for the first 10 years were lower than for grand fir and Douglas-fir, but higher than for lodgepole pine and Sitka spruce (Holmsgaard and Bang 1977).

Seral Status

Throughout most of its range, Port-Orford-cedar seedlings can establish themselves in quantity during early stand development, after disturbances in stands, or under an intact, old-growth canopy. The species appears to be unusually effective in this dual role of early seral invader and shade-tolerant climax species. Near Coos Bay, it was the first tree to reappear after extensive fires (Sargent 1884).

Its role as an invader of disturbed areas is also apparent on most clearcuts where a seed source existed. Establishment continues after initial crown closure in clearcuttings, but ceases after a few years in dense stands, where understory may become virtually absent. As the stand ages, establishment of this shade-tolerant tree occurs again (see table 43). In old forests, all sizes of classes of cedar are present in all communities (Hawk 1977). Some stands have two or more important size classes, which appear to have resulted from repeated fires (Hawk 1977). One exception occurs on some higher elevation ultramafic rocks near Powers, OR, where dominant cedars have an understory almost entirely of western white pine, and little cedar establishment has followed a cut that removed much of the overstory.

A contrasting behavior is recorded in the California montane forest (Sawyer and Thornburgh 1977). Colonizing ability (the ability of species to reestablish quickly on suitable sites after fire) is listed as low for Port-Orford-cedar—below that of mountain hemlock, Douglas-fir, white fir, Shasta red fir, and Brewer spruce.

Franklin and Dyrness (1973) emphasize the early seral role of Port-Orford-cedar but do not believe it capable of competing in the shade. Our arguments to the contrary are presented in the section, Shade Tolerance.

Competitive Ability

The attribute of competitive ability is defined by Sawyer and Thornburgh (1977, p. 722) as "the capability of individuals of a species to grow and achieve dominance in competition for light, water, nutrients, and space with individuals of other species." Port-Orford-cedar is credited with high competitive ability on granitic and metamorphic parent material in the western ***Abies concolor*** zone of the montane forests in California, on wet to wet-mesic sites; only white fir is higher in this ability. In mesic sites on the same substrate in the higher Californian ***Abies magnifica*** zone forests, it has moderate competitive ability on mesic sites—lower than Shasta red fir, Brewer spruce, and mountain hemlock but higher than white fir. A somewhat different relationship apparently holds for the northern end of the range, where Port-Orford-cedar is almost always smaller than Douglas-fir by the time the tree reaches commercial size.

Another aspect of competition is the effect that a species has on its neighboring trees. For example, does the presence of a moderate to small amount of Port-Orford-cedar affect the productivity of the Douglas-fir in a stand? The definite opinion of several forest managers in Oregon is that Douglas-fir volume will not suffer from the presence of some cedar in a stand; some thinning prescriptions presently in force are based on this perception. This failure to interfere with Douglas-fir growth may result from an enhancement of soil properties by the cedar litter, from cedar's slower early growth, and cedar's lower (shade tolerant) crown.

Factors Limiting Distribution

Determining what attributes of the environment and the plant limit the distribution of a species is complicated; an unequivocal or universal answer may be impossible. Enough information is available, though, to suggest promising working hypotheses for Port-Orford-cedar, and we will review and somewhat expand upon those discussed by Zobel and Hawk (1980). The patterns of distribution vary with the scale of the area being considered; we present suggestions for four levels of scale—microenvironmental, topographical, regional, and geographical.

Microenvironmental level.—Little information is available about control of establishment of single individuals of Port-Orford-cedar or even about distribution patterns at the microenvironmental level. Observations show that Port-Orford-cedar seedlings are more common on logs than on the forest floor in some sites; in other sites, the opposite is true. Some canopy gaps support much cedar, while other gaps are dominated by other species to the exclusion of cedar; and cedars often seem to have established outside the gaps. Hypotheses for which we have some evidence (Zobel 1980, Zobel 1983, Zobel and Hawk 1980) are: (1) Soil moisture must be available at or near the surface all summer, both for initial establishment and later for good growth and reproduction. Season-long high water potential is probably necessary because germination is delayed until June; because cell division, twig elongation, and exposure of new foliage continues throughout the summer; and because of the late-summer development in the reproductive organs, which are initiated in early summer and emerge from the protection of surrounding leaves within a month or two. (2) Young dense stands and some microsites in old-growth forest are too dark for cedar to survive. (3) Disturbance of the mineral soil increases initial establishment, survival, and growth.

Topographic level.—Throughout much of its range, cedar seems clearly limited to topographic situations that assure a consistent water supply: areas with moving subsurface or surface water of all sorts, lakesides, beds of intermittent streams, gullies, slumped topography with seepage, and slopes with a sufficient watershed above to maintain seepage. Measurement of water potential of conifer saplings across several such features demonstrated a gradient away from the concavity. Cedar were limited to areas with late summer potentials above –11 bars before dawn. Cedar can be limited primarily to stream valleys and lower slopes (see fig. 12) or to northerly slopes, especially those at low elevation.

Port-Orford-cedar is limited locally to soils with higher K and Mg availability than is western redcedar.

Regional level.—Much of the distribution of Port-Orford-cedar at scales larger than the local topography is associated with geologic pattern (see fig. 1). The concentration of cedar on ultramafic rocks is obvious almost throughout its range, and cedar is limited to ultramafics in many areas. The relative importance of cedar and its associates differs among geological substrates, as indicated above and in the community descriptions.

There appear to be several reasons for the relatively greater abundance of cedar on ultramafic rocks. It has lower concentrations of P, K, and, especially, N in its xylem sap, leaves and litter than do Douglas-fir, hemlock, and some other conifers grown in the same environment. It maintains a higher Ca:Mg ratio on ultramafics and produces litter high in calcium. It may require higher Mg than occurs in some nonultramafic soils. Cedar seems better adapted to grow on these soils than do the dominants in more fertile areas; furthermore, its competition for water is reduced on ultramafic areas. Where cedar grows, the weathering of the ultramafic rocks has produced a dense layer of fine clay that creates a perched water table and consistent seepage. The saturation sometimes associated with these areas further excludes tree competitors. On ultramafics, then, water becomes concentrated enough to allow the cedar to grow, and its most effective competitors are excluded or have their density and vigor greatly reduced. In more humid climates, at low elevations where western hemlock or redwood can grow, or at higher elevations inland, cedar is not restricted to ultramafic rocks, and is most important and largest on the most productive soil types.

Increased humidity compensates partially for soil moisture, and the species grows on more convex topography near the coast and at high elevations. Even so, it has an uneven distribution over the topography. In the Coos County Forest, cedar was originally concentrated not only in wet glade lands, but also in other areas not obviously distinct from those without cedar (see footnote 9). Cruise data (by 16.1-ha blocks) and topographic and geologic maps from the former Port-Orford-Cedar Experimental Forest were analyzed using multiple regression techniques to determine what factors were significantly associated with the volume of cedar in old-growth forest. Port-Orford-cedar volume decreased significantly at higher elevations, on steeper slopes, and on southwest aspects, and was significantly higher on Eocene sedimentary rocks than on the other four rock types. These factors, however, accounted for only 25 percent of the variability. Despite the high proportion of “unexplained” variability, the factors that were significant agree with other observations of species’ behavior relative to landform.

Geographic level.—One problem with trying to "explain" geographic limits is that the descriptions of the geographic range are too simplistic, are incompletely documented, or disagree (see Chapter 2). Cedar may have been eliminated recently from certain areas by harvest and management practices or by disease—a problem that will increase in the future. Even so, some suggestions about range limitation can be made.

Precipitation and its ratio to evaporation drop drastically east of the range; sufficient microsites wet enough for the cedar probably disappear. Near the south end of cedar's range, the ultramafic substrates usually associated with the occurrence of cedar disappear from major river valleys and high coastal ridges—locations where, farther north, cedar will grow.

At the north end of the range there are no single-factor explanations that are supported by evidence. A complex hypothesis can be considered, however: The vigor of the cedar's competitors increases rapidly north of Coos Bay, and factors favoring the cedar remain stable or decline. To compete, the cedar must grow faster, which seems to require a longer period of stem elongation. Trees in the open near Coos Bay already elongate for 5-6 months; this may be the limit to their season of growth as imposed by either environmental or internal factors. There are two possibilities for environmental conditions at the north end of the range that do favor Port-Orford-cedar: (1) The coastline from Coos Bay to Port Orford is oriented at 21° from the more usual coastal direction of north-south. Summer winds, predominantly from north to northwest, strike the coast here at a greater angle than elsewhere, perhaps forcing marine air farther inland. The lowlands around Coos Bay and the northwesterly opening of the Coquille River drainage allow easy movement of marine air inland during the summer. Observations of cloud and wind patterns support the idea of a summer marine influence being important in the southern Coquille Valley. (2) Sediments forming the Coast Range at about Coos Bay and south were derived from the Klamath Mountains, which have abundant ultramafic rocks. Farther north, sediments came entirely from the volcanic terrain to the east. Any residual ultramafic influence in the soils, which may favor the cedar at the northern end of its range, disappears northward.

Another possible factor affecting the northern limit is increased competition from western redcedar, whose importance may increase northward in response to declining frequency of fire (Edwards 1983). Edwards also notes that the expansion of importance of Douglas-fir, apparently the major competitor of Port-Orford-cedar, is geologically recent.

Changes with time.—The distribution and importance of cedar differ depending on the seral stage and stand age; a major influence seems to be fire. In some areas, cedar is presently invading clearcuttings, which appear to be drier than the habitat in older forests. More frequent fires on drier sites may have previously eliminated cedar from drier sites, and the local distribution appears to be expanding with clearcutting in the absence of fire (see footnote **4).** In moister, old-growth forests, repeated but less frequent or less severe fires appear to have allowed cedar to increase through time. The old cedar trees survived better than other shade-tolerant species, and cedar seedlings invaded under the remaining canopy more effectively than did other fire-tolerant conifers. In a few areas, however, stands with repeated fires in the past have large survivors but little cedar reproduction.

In 1907, C.A. Schenck noted that "In the sapling stage, fungi seem to play havoc in the plantations, a fact which may explain the small range of the species" (p. 60). To what area or fungus he is referring is not clear, however. Phytophthora lateralis, presently the only major disease problem in the native range, was not reported until 1952 (see Chapter 7), nor is there strong reason to believe it was important or even present earlier.

Comparison with other conifers.—Port-Orford-cedar appears to react differently to changes in environment than the more widely distributed Pinaceae with which it grows (Zobel and Hawk 1980). It disappears with reductions in water availability that do not affect cooccurring species. It does grow, however, throughout temperature ranges and across soil-type boundaries that cause major changes in populations of other conifers.

Summary.—The primary factor of importance in cedar distribution appears to be a consistent summer water supply. Topography, geology, and climate apparently have their effects by influencing water supply. Temperature alone seems to have little effect on the local or geographic ranges, except perhaps in a few high-elevation areas. Such a simplistic answer to a complex question may eventually prove to be quite misleading; for example, many of the local details of distribution are not described well and the apparent requirement for water may have been magnified by past effects of frequent or intense fires—but this is the hypothesis that best fits our present data.

Chapter 7: Pathology and Control of Port-Orford-Cedar Root Rot

The only serious pest in the natural range of Port-Orford-cedar is Phytophthora lateralis (see Chapter 6), a fungus that causes a fatal root rot of the tree. Since 1952, this disease has spread throughout much of the area that supports commercial forest. Unless management techniques are developed specifically to take into account the effect of the fungus, and are applied rigorously and consistently, there can be little or no commercial future for Port-Orford-cedar beyond harvest of existing stands. Information about the disease is essential if managers are to suppress the disease and produce future rotations of cedar.

Damage Caused by *Phytophthora lateralis* Root Rot

We do not know the exact size of losses resulting from the Port-Orford-cedar root rot epidemic because of unique features of the commodity, the market, and the economy. Port-Orford-cedar at one time was particularly important to the maritime Pacific Northwest, outside its native range, as a lead item in the large export and domestic ornamental nursery industry. This industry, without cedar, was worth $23,000,000 in 1969 (Loy and others 1976). Within its range it is the most valuable timber species. The ornamentals and timber industries have suffered successively from the root rot.

It is essential to understand the importance of Port-Orford-cedar for residential and farm plantings if one is to appreciate the root rot epidemic and its threat to the forest. Before the epidemic, ornamental Port-Orford-cedar were grown in hundreds of private nurseries, and seedlings were available at little or no cost from public nurseries. Nursery stock alone constituted a significant population of cedar, and trees used in landscape and specimen plantings, hedges, and windbreaks resulted in high densities of cedar in much of western Oregon, Washington, and British Columbia, north of the native range. In terms of their disease vulnerability, these plantings resembled a forest. This artificial forest was largely destroyed by *Phytophthora* root rot, its effect aggravated by urbanization. Preceding collapse of cedar production, direct losses to nursery owners from crop failure in Oregon approximated $500,000[20] through the 1950's. Indirect losses because of replacement of trees and costs of shifting to alternative crops probably were as great as the direct losses. Less tangible losses have been replacement costs met by individual property owners, depreciation of property values, and reduction in environmental quality.

Within the native cedar region, losses of timber are large, diverse, and as with the horticultural trees, frequently not tangible. Trees of all ages are quickly killed by root rot. The loss has been primarily from disease spreading into commercial stands where it is measured by value of trees killed and, more recently by cost of disease control. Few managed young stands exist because the species was silviculturally abandoned for two decades as a result of the threat of disease.

Mortality in old-growth timber is estimated to have peaked in the early 1970's at just under 10 million board feet annually and since then to have gradually declined to about 5 million board feet.[21] The reduction has been primarily due to depletion of the resource, but also to slower spread of the disease onto less vulnerable sites.

Prices of killed timber must be sharply discounted below green log prices. After the bark loosens, about 3 years after death, logs lose their value for export, especially if bark has been lost and the wood has been exposed to the sun. Sun-checked logs are worth less than half the value of a sound log.

Mortality in commercial young growth has occurred mostly on the gently rolling, narrow, 100-mile coastal strip between Hauser and Gold Beach, OR. The forest reclaimed much of the land after logging between 1880 and 1930 and widespread grazing, with new cedar densities on former cedar sites approximating those of the original forest. Because of poor market conditions, this young forest was not commercial in the 1950's when root rot first entered the region. Thirty years of additional growth and price increases makes most of this remaining timber commercial today.

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[20] Personal communication, 1981, William Wheeler, Oregon Department of Agriculture, Salem.

[21] Personal communication, 1978, personnel of Coos Bay District, Bureau of Land Management; Georgia Pacific Corporation; and USDA Forest Service.

Urbanization and small-tract subdivisions have spread ***Phytophthora*** throughout the young-growth cedar forest since 1950 (Roth and others 1957, 1972; Kliejunas and Adams 1981). Sixty-percent **loss** seems a reasonable estimate today. The cash value of this mortality, because of low prices for small logs (see Chapter 8), has not been great. Depreciation of real estate values has been substantial. These losses have, however, been partially compensated by regrowth of stands of adequate density but of less valuable species. The major loss is in expectation values (Baxter 1952) of the potentially valuable cedar. High-quality, second-crop logs from this coastal cedar might have maintained the market, though at a lower level, after the remaining 30-year supply of old growth on public lands is harvested, and partially bridged the gap until production on major holdings can be brought under sustained yield with effective disease management. It is not unreasonable that the forest manager have high expectation values for the young stands; their destruction represents a real and substantial loss.

Much regeneration has been killed, often on sites where the best stands once stood, where the fungus was introduced from contaminated roads or by elk or cattle. Again, these losses are only of expectation values, which are difficult to estimate. Even without root rot, young cedar, because of its comparatively slow growth, is valued differently by various managers, and a value assigned by the same manager may change with time. The presence or threat of root rot makes it even more difficult to establish appropriate management objectives for young cedar stands. On good soils, all diseased sites (except ravines and swamps) are adequately stocked with faster growing alternative species. Even though timber of these species is worth much less per unit, it is difficult to place a cash value on the dead cedar regeneration or, in fact, to claim that there has been a loss. When appraising regeneration losses, one must remember, however, that (1) good cedar has usually been worth substantially more than the more common conifers, (2) the highest unit area return in the region results from the proper mix of Douglas-fir and cedar, and (3) on most ultramafic sites, possible alternative species, where they exist, grow less well than cedar and are less valuable. Encouragement of regeneration and retention of young growth seem justified.

Two additional items need mention when considering damage from root rot. The serpentine mountains of the native Port-Orford-cedar region are floristically unique and particularly beautiful. Port-Orford-cedar is the outstanding tree on these sites and in some cases is the only species of commercial quality. When these sites become contaminated, they may no longer be regarded as commercial timberland for Port-Orford-cedar; the accompanying aesthetic loss is impossible to evaluate.

Manufacturing in the Port-Orford-cedar region is preponderantly of Douglas-fir; cedar is exported. The disparity in value between the two species is so great that bidding on timber sales with mixtures can become highly complicated and costly to participants (see Chapter 8). Some decision makers in the forest industry have regarded the cedar as a nuisance and have been unsupportive of efforts to protect it against root rot or to manage it. These attitudes may have contributed to understatement of root rot losses, to lack of support for disease control, and to carelessness in woods operations.

Background for Root Rot Control

There are no cures for root rot. Genetically resistant stock is not available. Tests of chemicals found to be effective against other species of *Phytophthora* are incomplete. If chemicals should function against *P. lateralis,* their cost and special application may limit their use in the forest.

Limiting or preventing cedar root rot must, for an indefinite time, depend on suppression through management. The only disease management strategy at this time is to enable cedar to escape infection. To make **loss** reduction by disease escape effective, management must be dedicated to the long-term goal, and silviculturists must thoroughly understand the tree and its environment, and how these interact to affect the disease.

Recognizing cedar root rot.—Root rot may be identified: (1) by the rapid death of individual trees, (2) by the distinctive symptoms, (3) by the characteristic distribution of disease through the forest, and **(4)** by the exclusive occurrence on Port-Orford-cedar.

Rapid death of the crown is distinctive and involves a loss of luster and a change in color from the normal green or blue-green to gold, bronze, reddish brown, and finally dull brown. Yellow tones, rather than bronze, may be more common in the sourthern part of the range. Damage to tree roots by the moisture-dependent, low-temperature fungus peaks during the cool, wet season, but crown symptoms lag because of prevailing high humidities. Moisture stress in late spring and summer results in the simultaneous death of the entire crown. Trees die without thinning of the crown.

Root symptoms arise as a result of fungal growth across root grafts between healthy and diseased trees (Gordon and Roth **1976)** or, most often, following direct fungal infection of the tips of fine roots. The fungus grows from the tips through the succulent tissues toward the root crown. Root tips lose their luster, become water-soaked and soon rot. Fine, suberized roots become dark brown, then almost black. They too rot within a few months, leaving a much depleted root system. Bark of main roots darkens somewhat or occasionally appears purplish. Discoloration of inner bark and cambium extends up the main roots through the root collar into the lower bole for a distance of roughly two stem diameters. This discoloration is a uniform rich brown ending abruptly along its upper margin, sometimes in short spires, against healthy, bright, cream-colored inner bark. Inner bark of the entire bole and branches finally browns following crown desiccation.

Root symptoms are most apparent in winter and spring. The color is lighter in summer and the transition from infected to healthy tissue less definite. The dead tissues may be dry and hard. Although the summer condition resembles the usual effect of *P. cinnarnorni,* confusion of the two is unlikely because *P. cinnamomi* root rot is absent from Pacific Northwest forests.

Care is needed to avoid confusing root rot symptoms and attack by ***Phloeosinus*** spp. bark beetles. Crowns of beetle-infested trees thin over several months and fade unevenly toward yellow, with the foliage often assuming a green-yellow-brown tweedlike mixture. Exit holes are numerous in the bark. Blazing the trunk bark discloses galleries behind the exit holes and irregular patches of dead, brown inner bark scattered through the cream-colored living tissue. Dust from recent attacks is evident on the bark and at the base of the tree. Root bark remains bright for some time.

Most of the distinctive, uneven distribution of root rot in the forest is accounted for by spotty introduction of the fungus superimposed on uneven distribution of the cedar. This is especially evident in the southern part of the range where cedar, like the fungus, depends heavily on seepage. Disease centers are most frequently correlated with wet spots. In the northern part of the range of cedar, where soil moisture is sufficient for cedar over more of the landscape, the irregular pattern of occurrence is more affected by the machines and animals that carry the fungus and by subsequent movement of surface water.

When contaminated carriers enter a water course, ditch, stream, lake, or bay, the aquatic fungus can become established on cedar where the roots are below the flood level. These influences result in scattered patches of infected trees connected by strands of damaged trees (USDA Forest Service 1975). No other pest produces this netlike pattern in the forest (most easily observed in aerial photographs).

Spread of root rot.—*Phytophthora lateralis* lives in infected roots and wet soils and moves when these are moved. Spores released by the fungus are readily transported in flowing and splashing water. Spore transport through the air is so rare as to be irrelevant to disease management (Trione and Roth 1957). During wet weather, the important carriers are elk, cattle, and machines (construction equipment, road maintenance equipment, and logging equipment, trucks and off-the-road vehicles). There is abundant circumstantial evidence that all these carry the fungus. In dry weather, the main carriers are hauled earth, gravel, and soil-bearing debris.

Transport of ball-and-burlap container and nursery stock and garden plants is particularly hazardous when these have grown in soils following diseased cedar. Because symptoms are so conspicuous, movement of the fungus in diseased cedar stock is less likely, except possibly for larger ornamentals where development of foliar symptoms may be delayed. Small cedars die so quickly that trouble is soon evident. Whether from a nursery or from the wild, infected trees usually are culled and do not move. Healthy but contaminated stock from the same sources is particularly dangerous. Boots of workers in muddy operations, such as salvaging killed timber or cleaning ditches, can transport the fungus, but boots of personnel performing ordinary forestry functions probably are not a threat.

History of the disease.—Phytophthora *lateralis* is an aquatic fungus active at low temperatures well suited to the soils and climate of the Pacific Northwest (Trione 1959, 1974).

The first report of *Phytophthora* root rot was in 1923 in correspondence by the Malmo Nursery in Seattle, WA, with the Pacific Northwest Forest and Range Experiment Station, Portland, OR:

> We are sending . . . plants which are affected with a fungus disease which completely encircles the crown of the root, thus killing it. . . . We have already lost several thousand dollars worth of cypress. . . . We sent species for examination . . . about a year ago . . . the disease prevails throughout the whole Northwest, killing cypress in the private gardens as well as in all nurseries, causing vast loss, as this Lawson cypress is used very much here. . . . So far in our nurseries the disease has attacked only . . . *Chamaecyparis* (referred to as cypress by the trade) *Lawsoniana* (Port-Orford-cedar), C. *lawsoniana* erecta viridis, *C. lawsoniana* alumii, monumentalis, etc. . . . the disease [has] never been noted to have been overcome by the plant. . . . It would probably be worthwhile to have a thorough study made of this disease as if it goes on unchecked it will eventually kill all cypress, including the Lawson cypress timber stands of Oregon?

J. *S.* Boyce, Station pathologist, visited the Malmo Nursery several times in 1923, making the following observations, among others:[23]

> . . . any disease which is so virulent as this one appears to be is potentially dangerous. . .
>
> . . . It may interest you to know that what seems to be the same disease has done considerable damage to a hedge of Port-Orford-cedar here in Portland. . . . All the stock is propagated from cuttings and pot grown before being set out in the nursery. Much of the stock at this nursery in the past came from France. In most cases, the other varieties are grafted to a C. *lawsoniana* root stock.

This correspondence shows that the disease was widely distributed in cedars in nurseries, landscapes, and windbreaks by the time it became known to pathologists. Although the trouble was initially reported as a “fungus disease,” two decades passed before the cause was confirmed and the fungus described (Tucker and Milbrath 1942). By this time, the disease was epidemic in the ornamental cedar industry and in hedges and windbreaks.

In 1952, 30 years after the alert was given in the Malmo correspondence (see footnote 22), the disease appeared in the native range of Port-Orford-cedar (Roth and others 1957). There was active commercial development in southwestern Oregon in the 1950’s, and the fungus was rapidly distributed by construction and landscaping. It quickly appeared along the roads and the banks of streams that crossed the roads and along woodland stock trails. Within 3 years, root rot was conspicuous along the populous coastal strip and up the settled river valleys of Coos and Curry

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[22] Unpublished, typed report, Nov. 7, 1957, “Early History of Port-Orford-Cedar Root Rot,” by John Hunt, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. 2 p.

[23] From unpublished data on file, Department of (Botany and Plant Pathology, Oregon State University, Corvallis.

Counties.[24] Less intensive activity and topography adverse to movement of the fungus delayed spread inland into the remaining commercial forest and high mountains. Several locations were noted within the Siskiyou National Forest by 1960 and one at Gasquet, CA.[25] Spread is continuing there where it accompanies road construction and logging, and, at least in some sites, appears to be aggravated by an increasing elk population.

The origin of Phytophthora ***lateralis.***—The origin of P. lateralis is unknown; however, three views predominate: (1) that P. lateralis is endemic within the cedar region, (2) that it was introduced from Europe or Asia, and **(3)** that it is endemic in the Pacific Northwest outside the Port-Orford-cedar region.

Root-infecting fungi can live in a biologic community without causing conspicuous symptoms in their host (Garrett 1981). Phytophthora is well known for such behavior. For example, Middleton and Baxter (1955) report isolating ***P. cactorum, P. cryptogea, P. parasitica,*** and ***P. cinnamomi*** from roots of native plants without symptoms in pristine locations within the Port-Orford-cedar region. These authors may have misjudged the pristine nature of their location. They overlooked the extensive grazing and mining activities that occurred in the region around the turn of the century. Particularly suspect are the extensive transport of water for both mining and irrigation and the ubiquitous kitchen gardens of the Chinese miners of the era. ***Phytophthora*** lateralis was not among the fungi recovered nor would we have expected it; no host for it has been found except Port-Orford-cedar, and cedar shows symptoms soon after infection.

It seems equally unlikely that the fungus has been reactivated by human activity in recent decades to become a troublemaker. This has occurred with some plant diseases (Garrett 1981) and is reported for ***P. cinnamomi*** (Shepherd 1975). If the fungus were to reappear because of disturbance, it should have emerged long before 1950 as parts of the cedar region were subject to disturbance (farming, logging, road construction, mining, and urbanization) for 100 years before the first trees died from Phytophthora.

It is more reasonable to accept the fungus as introduced. It might have immigrated unassisted to southwestern Oregon from the infested Willamette Valley, but this seems unlikely for a fungus having waterborne rather than airborne spores. The valley and the Port-Orford-cedar regions are separated by an uninterrupted forest of immune Douglas-fir, precluding root-to-root spread, and by the Coast Range, which would prevent migration of the waterborne spores. The initial occurrence of root rot near recent landscaping indicated that spores were probably introduced with nursery stock grown in contaminated soil outside the cedar's range.

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[24] Processed survey reports, **1956** and **1959,** "Port-Orford-Cedar Root Rot Survey: and Phytophthora lateralis on Port-Orford-Cedar," by John Hunt, U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

[25] Collection by Lewis F. Roth.

Arguments that *P.* lateralis was introduced from Asia are based on the high resistance of the Asiatic species of Charnaecyparis to root rot. Scientists recognize that disease resistance may emerge through coexistence of a species with its pathogens over thousands of years. Consequently, the land of origin of resistant trees is a good place to seek the origin of their pathogens. In spite of the advanced level of *Phytophthora* research in the Orient, however, *P.* lateralis has never been reported in Japan or Taiwan.

The notion that *P.* lateralis was introduced from Europe seems even less probable than introduction from Asia. The many competent European mycologists, including Phytophthora specialists, have never found *P.* lateralis there, and Europe has no native Charnaecyparis, the only host. The misleading, often repeated, suggestion that *P.* lateralis was introduced from France probably is due to misinterpretation of correspondence reproduced in the section on history of the disease. The correspondence clearly communicates that Washington nurseries were widely infested before 1922. The losses are reported from liner stock in the nurseries and from private plantings, not from the French stock. In fact, the disease progresses so rapidly that stock infested in France never would have reached America alive given the transportation available in the 1920's.

That *P. lateralis* arose in the Pacific Northwest outside the cedar region also seems unlikely unless there is an undiscovered host capable of sustaining the fungus. Such a discovery seems improbable because of research over many years and 60 years of observation of the cedar disease in conditions that exposed the fungus to hundreds of species of wild and cultivated plants. Prior to development of a horticultural industry around Charnaecyparis, there was no known host for the fungus outside the cedar region.

That *P.* lateralis might be harmlessly endemic within the range of Alaska-cedar, which is resistant but not immune (Torgeson and others 1954), has been suggested? Possibly it behaves in the Alaska-cedar range like the *Phytophthora* species on wild plants in southern Oregon (Middleton and Baxter 1955). Roth (see footnote 26) suggested that when the artificially created forests of ornamental Port-Orford-cedar converged in southwestern British Columbia in the native range of Alaska-cedar, the harmless parasite on Alaska-cedar crossed onto the susceptible horticultural Port-Orford-cedar and spread aggressively southward. Although there are no reports of the fungus in native stands of Alaska-cedar, as for Asia and Europe, research on root diseases of native Alaska-cedar is limited; it is currently being expanded.

Schenck's (1907) observation, "In the sapling stage fungi seem to play havoc in the plantations, a fact which may explain the small range of the species," casts a final shadow of uncertainty over the origin of root rot. Schenck worked in both Germany and the United States, and the statement is too vague to tell which plantations he had in mind. So far as we know, there were no plantations at that time in southwestern Oregon. In 1907, diseases of the fine roots of trees were also relatively unknown to science. Hunt (see footnote 22) also is confident that Schenck was referring to something other than root rot.

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[26] "*Phytophthora*, whence and whither," presented by L.F. Roth to Pacific Division, American Phytopathological Society, San Francisco, 1977.

Biology of the fungus.—*Phytophthora* lateralis has been studied extensively (Englander 1973; Trione 1957, 1959) in the laboratory but inadequately in the field. Infectious spores (zoospores) of *P.* lateralis form only in water when soils are saturated. Unlike spores of most fungi, which are airborne, zoospores swim and are splashed and washed about in surface water. Zoospores infect unsuberized root tips or, after winter storms, fallen green foliage. On the surface of infected tissue, soon after infection, the fungus produces hyphae that bear lemon-shaped spore sacs (sporangia), each of which releases 25-50 zoospores into the surrounding water.

Vegetative growth of the fungus is confined to the living host tissue. It does not occur independently in the soil (Ostrofsky and others 1977). Within the cambial region, the fungus seems to grow indefinitely until the entire root system is colonized, regardless of tree size. This may require a year or more in a large tree. The fungus lives vegetatively as long as the infected tree survives. Extension to new trees can occur through root grafts (Gordon 1974).

Within the host tissues, two kinds of thick-walled resting spores may be produced: asexually formed chlamydospores and sexual oospores. Both become incorporated into the organic fraction of the soil when the infected succulent tissues decompose. These spores can live for months, possibly years, and are the principal fungal forms moved in mud. They are also believed to be the primary means of survival through summer drought and other unfavorable periods. In saturated soil, both kinds germinate to produce single zoosporangia that return the fungus to the active infectious state.

Development of the disease.—As noted previously, active fungal growth occurs only in living tissues. While small succulent seedlings are killed in only a few days, large timber may survive several years after initial infection. Most of the vegetative development of this fungus is within the protective host tissues. In spite of a possible harsh soil environment, survival is assured as long as the infected tree is alive. Because infected trees always die and the fungus cannot grow outside the tree, effective spread of the fungus to neighboring trees is necessary to perpetuate the disease.

The structural root system of native Port-Orford-cedar consists of a fan of large roots that taper away from the root collar through the upper soil. Above these, in the humus layer, is a dense tangle of fine roots formed from the tips of "humus-striver" roots, which grow vertically from the structural roots (Gordon and Roth 1976). These fine roots produce many succulent tips at the soil surface that are readily accessible for infection by spores of **Phytophthora** being carried in the surface and soil water. The fine roots are probably also the site of most sporangial production. Because of this close association of host and fungus at the soil surface, **Phytophthora** root rot is particularly infectious for a fungus that lacks aerial transport.

Wounds are unnecessary for infection to occur. The swimming spores come to rest along the fine roots between the tip and point of first formation of bark. Fungal strands (hyphae) germinating from these spores penetrate directly into succulent tissues. Because fine roots of trees of all ages are alike, there appears to be little reason to expect resistance to change with tree age.

Vegetative growth of the fungus through inner bark and cambium of main roots probably continues throughout the year. By the time the root collar is invaded, the tree is so stressed that it dies from desiccation when exposed to drying conditions of spring and summer. The contribution to the disease cycle of vegetative growth within the tissues is not known, except that in the undisturbed forest, vegetative growth provides the means for relatively slow but unassisted spread uphill of fungi. In dense stands, fungal growth from tree to tree may occur through abundant root grafts (Gordon and Roth 1976). Knowledge of these tendencies enables the manager to prevent uphill spread by establishing appropriate tree spacing. Green foliage whipped to the ground by winter storms also may become infected by splashed zoospores. Fallen dead foliage probably is not infected, particularly in competition with saprophytic fungi (Ostrofsky and others 1977).

Chlamydospores form quickly in parasitized fine roots and freshly fallen branchlets. These enable dormancy and longevity of the fungus. Decaying, spore-bearing tissue becomes part of the organic fraction of the soil from which the fungus, in the absence of infected living tissue, can be most readily, but not easily, recovered (Ostrofsky and others 1977). How old this material can be and still yield living fungus (be infectious) is not known, but it is certainly several months and possibly a few years.

Fate of mycelia that invade the structural root system and girdle the tree at the root collar is unknown. They may produce chlamydospores, sporulate at the surface after penetrating the thick bark, extend to the far side of the root system to sporulate there on fine roots, or sporulate again on the now dead roots at the point of initial attack. These matters can, in part, determine how long a site remains infested. Forest managers require an estimate of this longevity. Until the appropriate studies are completed, we suggest a minimum of 3 years.

Unassisted spread of root rot outside the host is limited to periods when soils are saturated. Because this fungus sporulates actively at cool temperatures (Trione 1974), spread by splashing rain and by washing occurs throughout the 5-month wet season after soils become saturated.

This fungus is confronted with real obstacles to wide natural dispersal, especially where topography is steep. Flowing water containing spores is quickly channeled into narrow waterways, leaving most of the terrain beyond reach of the spores. Vegetative extension through the stand is stopped by gaps in the cedar stand. Only with some agent to carry it can the disease be epidemic on wild land.

Wide distribution of cedar root rot resulted from shipment of nursery stock in infested soil. In the cedar region, local distribution and intensification resulted from earth movement during construction and road maintenance. Runoff from contaminated areas resulted in general infestation of water courses, lakes, and sloughs. Epidemic conditions have been most severe and most visible where human activity has been greatest. Damage is presently less visible and in some places less intense because surviving trees are on less accessible sites. On accessible sites with good soils, much mortality is screened from view by replacement vegetation.

Some slowing of the spread of the disease has accompanied leveling off of construction in the region, and the disease is forced to depend on less efficient, natural means of spread.

The disease continues to appear occasionally in seepage areas in quite remote places. This probably results from being carried by some unidentified animal or from some unknown human activity.

The response of disease to environment.—Root rot appears not to be influenced by soil type. It attacks equally cedars on soils derived from sedimentary rocks near the coast, on ultramafic soils in the mountains, and on deep, sandy loams in the northern Willamette Valley.

Active parasitism requires favorable temperatures when soils are saturated. Unlike many root-infecting *Phytophthora* species, I? *lateralis* thrives at the low soil temperatures that prevail during wet weather in the maritime Pacific Northwest. It is not inhibited by milder temperatures.

Temperature indirectly affects the disease by influencing drying of soil and the duration of dry periods that debilitate the fungus. Climatic differences within the cedar region influence the amount of disease: The rate of disease development among trees generally is slower in the warmer and drier parts of the region. This effect is confounded, however, by lower density of cedar in the drier country.

Soil moisture is by far the greatest environmental influence on root rot; the longer the wet season and periods of soil saturation, the more abundant the disease.

Characteristics of epidemics.—Understanding how epidemics work can aid management for disease control and will help the manager develop special procedures to meet particular disease situations.

All epidemics share the three essential components: (1) large populations of susceptible hosts, (2) abundant inoculum, and **(3)** favorable environment. Cedar root rot also requires some means of transmitting the inoculum. If all components are present in optimum amounts and are ideally timed, the epidemic will be severe, and trees will become infected at a high rate. (These conditions were approximated as cedar root rot developed along the coast of Coos and Curry counties.) Any reduction of an individual component will reduce the probability of infection. Wide spacing of the cedars, reduction of inoculum, carrying out forest management operations in dry weather, and reduction of carriers of spores can be used individually or jointly by the manager to dampen an epidemic.

Genetic Resistance to ***Phytopthora lateralis***

Although there has been no general screening of seedlings for resistance to I? *lateralis,* thousands of cuttings have been tested from several hundred trees that survived among dead associates. All tested cuttings died. This suggests either that the parent trees escaped infection and there was no resistance to root rot or that inoculation during testing was too severe. Extended survival of some trees may be an inherited trait that can be genetically strengthened to provide a usable degree of field resistance. This hypothesis should be tested.

Chapter 8: Management Considerations

Appropriate future management of Port-Orford-cedar will differ substantially from that of other species. It must include consideration of (1) the market peculiarities, which for cedar differ from those of other commercial timbers; (2) cedar's potential uses, which are not reflected in the current export-dominated market; and (3) the details of the major disease, which limits the commercial range and complicates production.

History of Use

The primary uses and markets for Port-Orford-cedar changed drastically within its first century of use as a commercial timber. Aboriginal Americans and European settlers, who entered the range of cedar in the early 1850's, used it for a variety of purposes, including housing, furniture, and fuel (Beckham 1973a, Beckham 1973b, Peterson and Powers 1952). A mechanical sawmill produced lumber for coastal Oregon gold mines (Oregon Historical Records Survey 1942), and a second mill, at Port Orford, sawed the first lumber shipped to San Francisco in 1853 (Knapp 1981). By 1857, cedar lumber was the highest priced and most useful wood sold in San Francisco (Kellogg 1857, also see appendix). Cutting for the California market expanded to mills along the Coquille River and around Coos Bay; by the late 1860's the latter area produced most of the cedar lumber cut (Beckham 1973b). Early consumption of Port-Orford-cedar wood was apparently limited to the Pacific coast: two prominent dendrologists from the eastern United States made a special side trip to Coos Bay to see whether cedar lumber used in Portland, OR, came from the tree they knew as the ornamental Lawson's cypress (Sargent 1881). The species had become a popular garden tree in Europe after British plant collectors obtained seed from interior California in 1854 (Gordon 1875, Murray 1855a, Murray 1855b).

Early uses of the wood were many and varied (fig. 29). Production increased substantially in the 1880's, after 1907, and during World War I when larger mills were built (American Lumberman 1911, Douthit 1981). The boom in cedar production during most of the 1920's and 1930's was based on its use in automobile storage batteries (1 billion wooden battery separators were produced at Coos Bay in 1936 [Lamb 1938]), export to Japan and Europe (50 percent of production from Coos and Curry Counties in 1923 to 1935 was exported [Oregon Historical Records Survey 1942]), as well as traditional domestic uses. These specialized uses kept cedar mills running during periods of severe depression in the rest of the timber industry (Douthit 1981).

Following World War II, substitutes were developed for two major cedar products, venetian blind slats and battery separators, and the price and use of cedar had plummetted by the early 1950's (Stillinger 1953). The export trade with Japan began again, however, and soon dominated the cedar market. In 1981, the primary domestic cedar product was produced by three arrowshaft mills (Associated Press 1981), with one small mill each producing custom-sawn lumber for export and bleacher seating.

Partial List of Uses for Port Orford Cedar

Airplanes
Arrowshafts
Baskets
Beehives
Blinds, venetian
Boards, boat
Boards. drain
Boats
Bowls
Brushes
Broom Handles
Cabinets
Casings, house
Chests, clothes
Closets, linen
Crates
Crating
Culverts
Decking, bridge
Decking, ship
Doors, house
Doors, screen
Dowels
Drawers
Finish, house
Finish, hospitals
Fixtures
Flooring blocks
Frames, boat
Frames, mirror
Frames, picture
Furniture
Gauges, gasoline
Greenhouses
Grills
Handles, paint
Hangers, garment
Icing Platforms
instruments, musical
Instruments, scientific
Keys, organ
Launches
Lawn Furniture
Linings, closet
Mantels
Matches
Mine Timbers
Mouldings
Novelties
Organs, pipe
Paper Mill Machinery
Paving Blocks
Pergolas
Piling
Planking, boat
Plywood
Poles, curtain
Poles, telephone
Posts, guard
Presses, filter
Rolls
Sash
Screens
Separators, battery
Shells, racing
Shelves
Ships
Shoes, sash
Siding, house
Sills
Silos
Stools
Strips, sash
Tables, card
Tables, novelty
Tanks, water
Toys
Trim, house
Tubs
Tunnel Timbers
Turnings
Vats
Vehicle Parts
Veneers
Wardrobes
Windmills
Woodenware
Yachts
Yardsticks

Figure 29.—A partial list of uses for Port-Orford-cedar given in an advertising and information bulletin (Port Orford Cedar Products Co. 1929).

Use of the Exported Wood

The Japanese buy Port-Orford-cedar lumber as a partial substitute for their native hinoki, which has traditional uses in construction of houses and temples but is in very limited supply. “Flawless hinoki is held in religious veneration by the Japanese’’ (Lamb 1929, p. 39). The Japanese market has taken essentially all the large green timber produced in recent years.

Under present conditions of nearly exclusive export and high values, logs are separated into two groups, those less than 30 cm diameter and those larger. The units with logs of mixed quality and size may be sold either at auction or to a single agent. When large quantities of cedar are included in a federal timber sale, agents of one of several large Japanese trading companies may purchase stumpage on bid after detailed examination of the individual cedar trees and consultation with their client. Trees are felled with care, in some cases using cables to control the fall.

Logs are graded by the Japanese into the five quality ratings: large logs with 90 percent, 75 percent, 50 percent and less surface clear, and utility (logs less than 30 cm and those with little clear surface). Within the higher quality classes are further subdivisions by size. Within any one quality-diameter grouping, however, price can vary considerably based on wood characteristics. Second-growth wood is used only when concealed as floor joists or framing. Eight to ten rings per inch has been considered coarse-grained.

Prices of Port-Orford-Cedar

Port-Orford-cedar wood has commanded a premium price throughout most of its commercial history. Its early price in San Francisco was at least twice that of Douglas-fir and redwood (Cox 1974, Appendix I; Dodge 1898). Stumpage before the Great Depression rose to $18/MBF (thousand board feet) (Oregon Historical Records Survey 1942). Following World War II, when domestic use declined and before export to Japan was reinitiated, cedar stumpage fell to $2-4/MBF. Cedars were often left standing after harvest cutting and logs were cut into ungraded dimension stock. By the early 1960's, prices for export were higher than for Douglas-fir and rising (fig. 30). In 1981, logs exported from the Powers Ranger District, OR, sold for an average of $2,166/MBF.

A high price for Port-Orford-cedar requires clear, fine-grained old-growth of large diameter (see Wood Properties, Chapter 5). Port-Orford-cedar is high on a list of replacements for the Japanese native hinoki: Taiwanese ***Chamaecyparis*** is the first alternate, and Port-Orford-cedar is second, followed by Alaska-cedar, Sitka spruce, and noble fir ***(Abies procera*** Rehd.) The demand depends on the price and quality relative to the several alternative woods available. During the late 1960's, prices of Port-Orford-cedar in Japan rose more rapidly than for any other wood except hinoki and exceeded those of other American imports (table 63).

Log prices vary considerably with size and quality (table 63). Before a 1981 slump in the market, utility-grade logs (defective or less than 30 cm diameter) brought up to $300-400/MBF in the United States, and the highest quality large logs brought $2,000 to $6,000. Decks of mixed-quality logs 30 cm and larger have sold for $500 to $1,800/MBF in recent years. Much young cedar from farm woodlands is open-grown, has characteristically poor form, coarse grain, and many knots. It is derogatorily termed "farmer's cedar" and sells as "utility grade'' at a flat price when there is a market. During the 1981 slump in the market, second-growth utility-grade logs were selling on the domestic market for as low as $135/MBF.

Bids for stumpage varied from $1,000 to $5,000/MBF in the Siskiyou National Forest in 1980-81. The high bids were based on expectation of yield exceeding the official estimates, from speculation on future price rises, and in some cases on ignorance of the realities of the market. In other cases, the cedar may be the only biddable item in a mixed-species sale, or the bidder may bid high on a small cedar volume to get the Douglas-fir. The presence of cedar occasionally inflates the price bid for Douglas-fir. To discourage playing games with the bidding, some management units have excluded the cedar from the bidding, and others have tried to concentrate the cedar into sales separate from those sales including primarily other species. Other managers allow bidding only on species that comprise more than a minimum percentage of the sale.

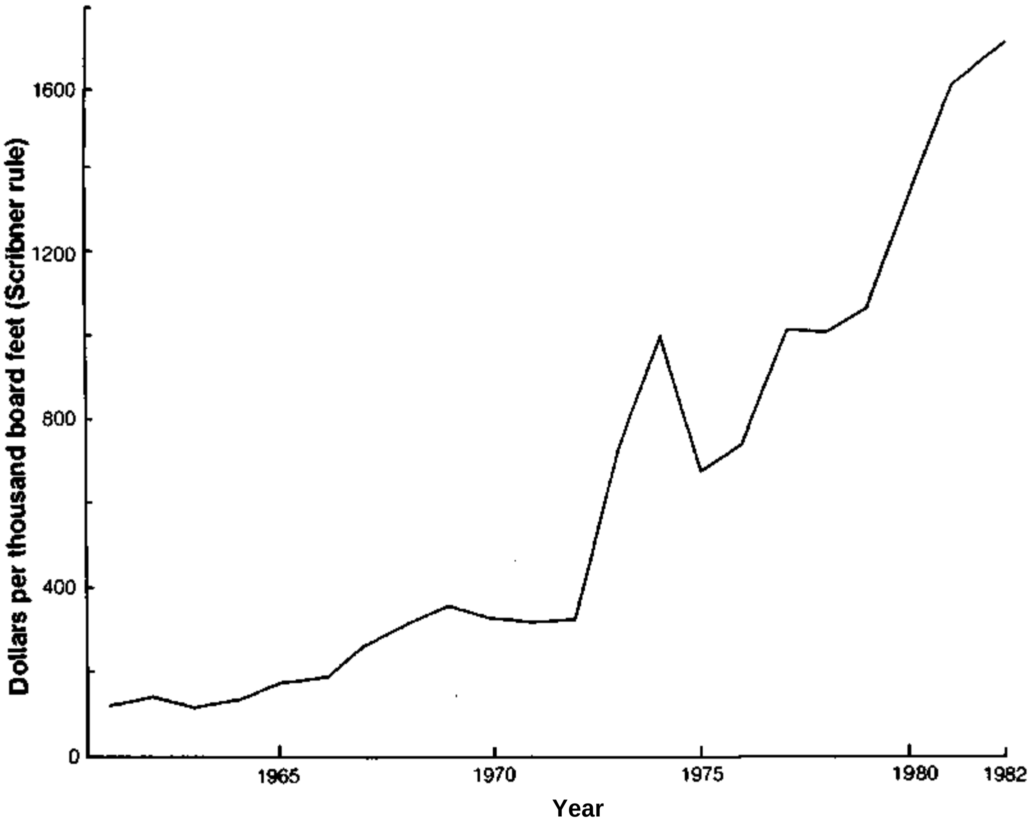

Figure 30.—Log prices of Port-Orford-cedar exported from Oregon Customs District, 1961-81, in dollars per thousand board feet Scribner scale (Ruderman 1979, 1982).

Table 63—Wholesale prices (dollars per thousand board feet) of Port-Orford-cedar logs, Japan, 1965-70, compared to other imported species and small hinoki[1]/ logs by species, Japanese log grade, and log diameter

(In dollars)

Year	Hinoki, 1/ all grades, 14-23 cm	Port-Orford-cedar No. 3, 30+ cm	Port-Orford-cedar No. 2, 46+ cm	Port-Orford-cedar No. 1, 61+ cm	Sitka spruce, No. 1, 76+ cm	Noble fir, No. 2, 46+ cm	Douglas-fir, No. 3, 30+ cm	Western hemlock, No. 3, 30+ cm
1965	214	205	336	522	252	208	153	152
1966	266	224	433	672	272	239	158	153
1967	354	306	651	974	312	294	170	162
1968	391	323	622	917	350	318	177	171
1969	446	327	626	975	388	249	188	177
1970 2/	455	328	632	1020	375	259	197	178

y Chamaecyparis QDtusa.

'II First quarter only.

Source: Austin 1970.

Certain types of salvage are reserved for use as short bolts and are intended for arrowshafts, but recently some short bolts have been exported. Prices for arrow bolts were $6-47 per cord in the field and $90-150 at the mill in 1981; the same type of material exported during a strong market in about 1980 brought $300-400.

Timber Production and Supply

Size of harvest.—Total volumes cut are not available for the early years. Forty million board feet were cut in Oregon in 1916 (Henley 1973) and about 50 million in 1920 (Peavy 1922). The cut rapidly increased during the 1920's in Oregon; the 1925 cut was 59 percent lumber, the rest veneer stock and squared logs (Dion 1938). Oregon log production (fig. 31) dropped drastically during the early depression years, recovered through World War II, and then declined again. The volumes given as "log scale" in figure 31 are below those quoted by Dion (1938) for the 1920's. Henley (1973) cites the 1940-43 cut as averaging 62 million board feet for lumber and 29 million for veneer and other uses (well above amounts shown in fig. 31). In 1960, domestic consumption was less than 1.7 million board feet; it was probably below 0.5 million by the 1970's (Henley 1973).

The percentage of Port-Orford-cedar in the timber harvest has exceeded its proportion of the timber supply, and concern about overcutting was expressed even by earlier writers. In Coos and Curry Counties, cedars accounted for 23 percent of saw-log production in 1925-29; 14 percent in 1930-40; and 11 percent in 1940-44. In contrast, it accounted for only 3.2 percent of the sawtimber supply (Marquis 1947); the comparable estimate was 14 percent in 1902 (Gannett 1902).

The volume exported in log form (most of that harvested in recent years) has declined since 1961 (fig. 31). The relative importance of Port-Orford-cedar in the export market has also declined, although cedar's high price has kept it as a higher proportion of export value than of volume (fig. 32). During most years between 1961 and 1982, over 99 percent of exported Port-Orford-cedar went to Japan (Ruderman 1979, 1983).

The Powers Ranger District, Siskiyou National Forest, OR, is the major producer of cedar. In the early 1980's, 5 to 7 million board feet of cedar was cut there annually (10 to 14 percent of the total harvest from the district); in addition, 0.3 million board feet of arrow stock was removed and a like amount of other wood salvaged per year.

Volume of growing stock.—The most recent estimates of total remaining growing stock are 4.6 million m^3 for Oregon (52 percent on Federal lands) and 1.2 million m^3 for California (Ohmann 1982; footnote 27). Half the growing stock volume is in Coos County, OR. Table 64 gives the available county-by-county estimates. Volume is concentrated in larger trees, especially in California (table 65). Growing stock in Oregon was 7.5 million m^3 in 1948 (Moravets 1951). Board foot volume in Oregon at the turn of the century was 2,652 million, 2 percent of it west of the Cascade Range; three quarters of the cedar was in Coos County (Gannett 1902). More recent board foot estimates (Scribner rule) have been: 1932-33—1,397 million; 1948—1,688 million; and 1963—933 million (Henley 1973). The present board foot volume in Oregon is probably about 450 million (Scribner rule), compared to the 240 million estimated for California (Kliejunas and Adams 1980).

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[27] Personal communication, 1982, Janet Ohmann, **USDA** Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon.

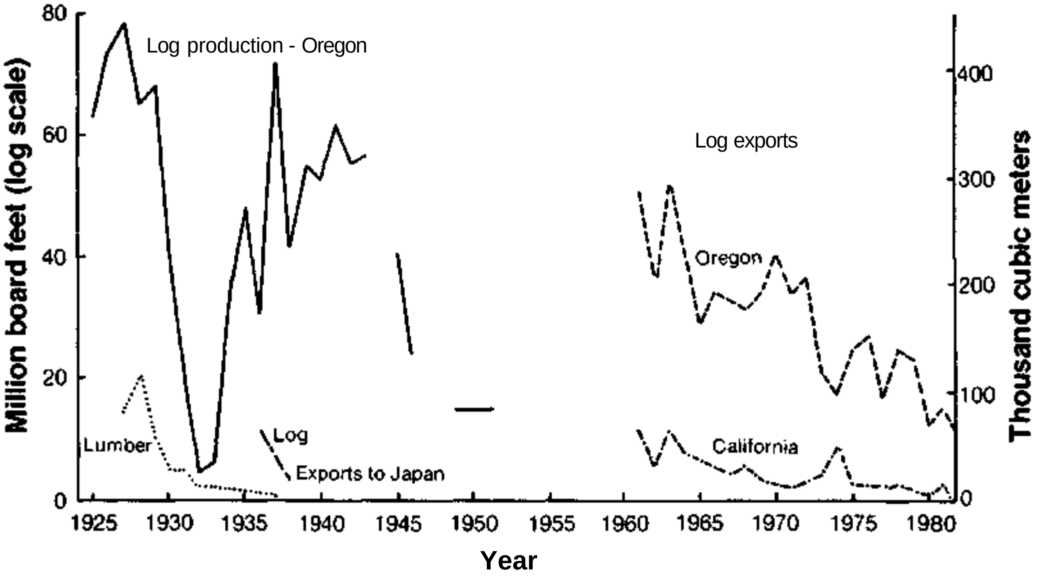

Figure 31.—Log production of Port-Orford-cedar in Oregon, 1925-51, exports to Japan, 1927-38, and log exports from Oregon and California, 1961-82. Values for 1949-51 are the estimated maximum. Data are given in million board feet, Scribner. (Data are from: 1925-51: Stillinger (1953); 1961-82: Ruderman (1979, 1983); exports, 1927-38: Elchibegoff (1949).)

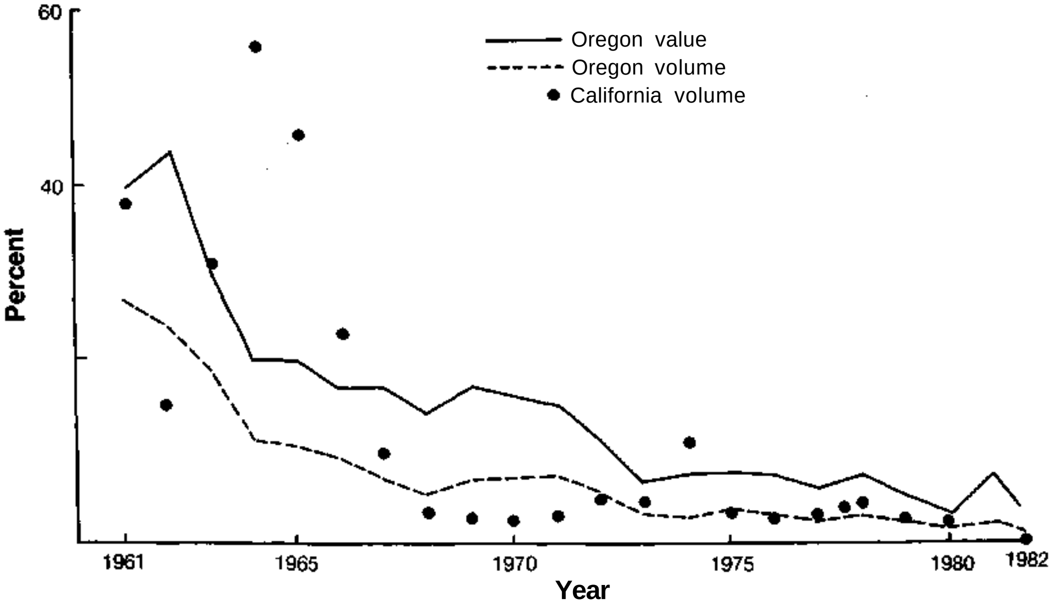

Figure 32.—Port-Orford-cedar log exports as a percentage of total volume and value of softwood log exports from Oregon and as a percentage of volume exported from California, 1961-82 (from Ruderman 1979, 1983).

Table 64—Forest survey information for volume and growth of Port-Orford-cedar, by county

County	Area in forest type	Volume of growing stock	Volume of sawtimber		Net annual growth		
			Scribner	International (1/4")	Cubic	Scribner	International (1/4")
	thousand ha	thousand m^3	- - - million board feet - - -		thousand m^3	- - - thousand board feet - - -	
Oregon:							
Coos	17.8	2,915	296	441	105.8	5,832	13,436
Curry [1]	7.7	255	12	23	7.3	-189	760
Josephine	1.6	198	25	29	2.3	ND	250
Douglas	4.1	ND	ND	ND	ND	ND	ND
California: [2]							
Humboldt	ND	28	ND	ND	ND	ND	ND
Shasta, Trinity, and Siskiyou	2.4	538	97	105	5.7	1,100	1,100

ND = no data available.

[1] Volume and growth on National Forest land are not included.

[2] No data for Del Norte County.

Source: Bolsinger (1976) for 1970 in Shasta, Trinity, and Siskiyou Counties, CA; for Oregon and Humboldt County, CA, for 1980, unpublished data on file, USDA Forest Service, Pacific Northwest Forest and Range Experiment Station, Portland, OR.

Table 65—Percentage of Port-Orford-cedar growing stock, Oregon and California, by diameter class

(In percent)

State	Lower limit of diameter class (centimeters)										
	12.7	18.0	22.9	27.9	33.0	30.1	43.2	40.3	53.3	73.7	99.1
Oregon	12	11	2	6	9	5	10	2	17	12	12
California [1]	t	t	--	10	t	5	10	t	14	25	15

-- = none; t = less than 3 percent.

[1] Excluding Del Norte County.

Source: From USDA Forest Service, unpublished data on file, Pacific Northwest Forest and Range Experiment Station, Portland, OR; Bolsinger 1976.

Growing stock volumes (table 64) were about 1 percent of the total softwood volume in the Oregon and California counties involved (Bolsinger 1976, Hazard and Metcalf 1964). Annual exports from Oregon from 1977 to 1980 averaged about 2.5 times the estimated net annual growth of sawtimber, and about 4 percent of Oregon's estimated present volume of Port-Orford-cedar sawtimber, a figure similar to Henley's (1973).

Small, unevenly distributed timber volumes, as those for Port-Orford-cedar, are subject to large errors of estimation (Bolsinger 1976), and estimates from different eras may differ because of changes in estimation procedures.

In Oregon, the 31 000 ha of Port-Orford-cedar forest type are owned by the forest industry (38 percent), the Federal government (30 percent), other private parties (20 percent), and other public agencies (12 percent) (Gedney 1982).

Production of Florists' Greens

Port-Orford-cedar branches are collected in the natural range for use by florists. One company in Coos Bay ships about 127 000 kg annually, with the major proportion in autumn. Collectors received $0.30 per 0.9-kg bunch in 1983; retail florists in western Oregon paid about $1.10/kg.

Collection is often by permit only, and collections per tree are supposed to be limited. Given little regulation, sometimes collectors strip most of the crown, which reduces cedar's relatively slow growth rate even further.

Past and Current Management Practices

Management of Port-Orford-cedar in the native range, other than by harvesting, has been limited. In 1910, defective trees were being left as seed sources and seedlings were grown in a Coos County nursery (American Lumberman 1911), but no information about early plantations is available. Limited planting in the northern Siskiyou National Forest in the late 1950's and early 1960's was discontinued when root rot caused nurseries to stop producing stock. Currently, with a fuller understanding of the root rot problem, the Siskiyou National Forest is planting cedar to supplement natural seedling establishment.

The earlier planting was of 2-0 stock at 2.4-m spacing in alternate rows with Douglas-fir; recently, container stock 20-30 cm tall was planted at 6-8-m spacing within and in addition to the regular Douglas-fir planting. Farther north in the Coquille River drainage, 25,000-50,000 cedars have been planted annually since the mid-1970's on industry land. Sufficient container stock, 30 cm tall, has been interplanted with Douglas-fir (fir at 2.7-m spacing) to form a third of the stand. Industry plantings have been confined to local areas without root rot, where no seed source was available. Experimental plantings for control of gorse were relatively successful (Herrnann and Newton 1968), but later were destroyed by root rot.

In many management units, no guidelines exist for the management of young cedar stands. The necessity to thin precommercially has not yet occurred in some areas. Events are now forcing decisions about management to be made in most of the cedar's commercial range, however, by default if not on purpose.

In the past few years, precommercial thinning in stands with cedar has become more common, and it will continue to increase. Some selection for and against Port-Orford-cedar has occurred. After 1962, cedar was specifically removed in some Forest Service thinnings; cedar was left as a crop tree only where Douglas-fir or hemlock were not available. Where the thinning criterion is size, cedar trees seldom survive. In some National Forest districts, minor species (including cedar) are consciously favored to increase stand diversity, although they represent less than 1 percent of the trees left. Recently in the Powers Ranger District, OR, the Forest Service has tested the practice of thinning cedar independently of the primary crop species. All cedars are removed in a 15-m band along streams and below roads; then, farther from potential sources of infection, they are left at 8-m spacings, so long as they are more than 1.2 m from a taller primary crop tree (usually Douglas-fir). The main thinning regime for Douglas-fir is at 3- to 5-m spacing. The wide spacing of cedar is designed to eliminate root overlap and reduce tree-to-tree spread of root rot. Precommercial thinning is done at stand ages of 10 to 15 years. Twenty years may be appropriate on poorer soils.

Few natural stands of cedar have been commercially thinned. In coastal Coos County, some thinning to a maximum 6-m spacing has been done. Thinning in dense stands increases the danger of windthrow and almost ensures introduction of root rot. No stands have been thinned during their development, so it is not known to what degree stocking control is possible.

Most coastal stands are cut at about 60 years when cedar is only of marginally commercial size, although some concentrations of cedar will be cut on longer rotations. Near the coast, danger of windthrow plus regeneration requirements of the desired species have precluded use of any harvest methods besides clearcutting.

Experience in Great Britain indicates that Port-Orford-cedar slowly fills gaps left by thinning; its shade tolerance and narrow crown suggest that stands should be left denser than those of most other conifers (Macdonald and others 1957). Natural pruning in dense stands is very slow (Macdonald and others 1957, Schenck 1907).

Early experimental plantations in the Pacific Northwest have been described only briefly (Duffield 1956, Hayes 1958, James 1958, Krygier 1958, Ruth 1957). Plantations established in southwestern Washington in the 1930's were damaged by a cold wave in 1955 (Duffield 1956); all that remain of some extensive ones in Cowlitz County are scattered understory trees.[28]

One plantation near Mapleton, Lane County, OR, was planted on an old pasture in 1942 (USDA Forest Service, no date). Stocking at age 37, after pole removal at about 30 years, was 1265 trees per ha (mean diameter 28 cm, basal area 63 m^2/ha). It was recently invaded by root rot and destroyed by wind in 1981.

Although the species will grow reasonably well in sufficiently moist habitats in many countries, its future in forestry outside North America is perceived to be quite limited. Forestry plantations have been made in several areas of Europe (Boullard 1974, Hamilton and Christie 1971, Hayes 1958, Holmsgaard and Bang 1977, Macdonald and others 1957, Schwappach 1911, Streets 1962), as well as in Australia, Ceylon, Kenya, Mauritius, New Zealand, and South Africa (Streets 1962). In no case, however, does Port-Orford-cedar seem likely to play a major role in forestry; other conifers are more productive on the sites where the cedar grows best[29] (Boullard 1974, Macdonald and others 1957, Streets 1962).

A Look Ahead: Management in the Presence of Root Rot

The cedar root rot epidemic appears so threatening for most of the Port-Orford-cedar range that interest has been expressed in nominating the tree for listing as an endangered species; however, the aggressive reproduction of cedar and natural restrictions on the fungus indicate that the survival of cedar as a species is not threatened. Survival as a commercial timber will be limited, though, unless successful management is achieved. Over the next 30 years, old-growth cedar probably will continue to be harvested, and to die from root rot at a declining rate paralleling exhaustion of the resource.

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[28] Personal communication, 1981, F. Nicoll, International Paper Company, Portland, Oregon.

[29] Personal communication, 1982, B.P. Glass, New Zealand Forest Service, Rotorua, New Zealand.

The only significant young growth (age 30 or older) available after the old growth is gone is along the coast. It is heavily depleted by development, is widely damaged by root rot, and (except for Coos County Forest) seems unlikely to be managed to reduce the disease. This timber will probably not outlast the old growth in the mountains. Realistically, it will be at least 100 years before the species can again be a major contributor to the economy of the region and that will come only with effective timber and disease management.

In this situation, undertaking special management may seem useless. Despite the problems, however, a well-planned, well-executed effort can be justified by the following: (1) The high per unit value of exported cedar generates a major cash return to forest land owners and, through payments in lieu of taxes on public land, a valuable source of revenue for local governments. (2) The highest cash return from the mountainous forest land in the northern part of the cedar range is realized from timber production by stands in which cedar is mixed with Douglas-fir, and in which the cedar is harvested at its appropriate rotation age. Cedar appears to compete little with the Douglas-fir, so the extra value cedar adds to the harvest is a bonus. (3) Cedar is the best growing species as well as the most valuable on many of the serpentine mountain sites common in the region. On some sites it is the only species that can reach commercial quality. (4) Much of the limited cedar forest is biologically distinctive and, in the southern part of the range, is ecologically and floristically unique, deserving special management for its perpetuation on these grounds alone.

By working cooperatively with natural constraints on the disease, sustained, informed disease management can succeed in producing healthy crops on much of the land in spite of the acknowledged obstacles.

Objectives of Cedar Management

These are several possible objectives for managing Port-Orford-cedar.

1. To allow cedar trees to escape the root rot disease. Success in this objective is necessary to achieve the other objectives throughout most of the commercial range. That situation may eventually extend throughout the botanical range.

2. To retain the species and its genetic diversity. The species is threatened on better sites by routine management for other species, which removes surviving cedars before they reach reproductive age. Loss of the genetic types on good sites would be tragic. These populations have the most potential for being used in case more effective root rot control measures develop or for being planted outside the range.

3. To retain biotic diversity, as mandated in the National Forest Practices Act, and aesthetic quality. Port-Orford-cedar is a beautiful tree; it is the largest tree on some ultramafic sites, and it is the most shade-tolerant conifer in much of its range.

4. To retain the apparent ameliorative effects of cedar on soil properties. Cedar litter is less acidic and higher in calcium than that of associated conifers. Foresters have suggested that the capacity to grow other trees on some ultramafic sites may result from the influence of cedar on the soil.

5. To produce additional revenue from forests managed on normal rotations for other species. Cedar may produce small saw logs on good sites in the course of a rotation; some foresters believe that the presence of cedar will not adversely affect the yield of the primary species.

6. To produce cedar as a primary product.

6a. Present market conditions require large, slowly grown, and therefore old trees. Areas dedicated primarily to production of high-value cedar, or areas managed on old-growth rotations for other reasons, are required. On poor sites where cedar is the primary commercial species, production of large, old trees may be the only commercial timber use possible. In all cases, the sites must be the least susceptible to introduction of the fungus, and the landholder must be dedicated to cedar production. A small market for an intermittent supply must be available.

6b. If the market for small saw logs develops, or if future markets develop in which mechanical, not aesthetic, properties of the wood are of primary value, shorter rotations to produce rapidly grown but smaller trees would be feasible.

7. To diversify the economy of the Port-Orford-cedar region. Commercial production of cedar brings economic diversity and the likelihood that a cedar market would allow for continued forest industrial activity in times of depression of the overall market, as has occurred in the past. Development of locally manufactured products would increase the economic benefit. Cedar production also supports minor industries, such as collection of florists' greens and production of arrowshafts.

General Guidelines for Future Management

Port-Orford-cedar can be successfully managed in spite of root rot. To minimize damage, management should strive to:

1. Minimize spread of inoculum (infested earth, mud, or gravel) during construction and maintenance of forest access roads.

2. Conduct forest operations and forest use in a sanitary way, particularly avoiding contamination caused by moving uncleaned equipment from infested to uninfested sites. Site contamination is a particular danger when timber killed by disease is being salvaged.

3. Concentrate cedar production as high above and as far from infection sources as possible without unreasonably limiting the amount of growing stock. Concentrations of cedar should be on high ground and well away from roads. The ratio of cedar to other species should decrease close to roads and on more gentle slopes.

Chances of successful management will be enhanced by two severe limitations on the fungus: (1) There is no secondary host for the root rot. (2) Natural spread of the fungus is by spores in surface water which, in the rough topography of the cedar region, mostly flows into narrow, natural waterways away from the growing stock.

Observations of Port-Orford-cedar throughout its range by many people for nearly a century indicate consensus on at least three aspects of productivity: (1) On good sites, at least during midlife, Port-Orford-cedar grows more slowly than most associated conifers. It is therefore not completely compatible with rotation ages desired for management of the principal species on these sites. (2) On extensive ultramafic sites, Port-Orford-cedar outperforms other species and may be the only species with future commercial potential that can be grown on such sites. Alternative species such as sugar and western white pines are plagued equally by disease. (3) On good sites in mixed stands, cedar is smaller than Douglas-fir and appears to be noncompetitive with it. Cedar can therefore be grown at little added cost and can be harvested at the appropriate time as a bonus to normal Douglas-fir yield.

Recent ecological work (summarized in Chapters 3, 4, and 6) has more specifically defined the forest types in which the cedar grows, and demonstrated differences in cedar growth rates associated with forest type. This work has also confirmed that Port-Orford-cedar apparently requires abundant soil moisture throughout the growing season, but appears to be less sensitive to cold, wet soils, to a wide range of air temperatures, and to soils of low or poorly balanced nutrient concentrations than are the major associated conifers. It has been demonstrated that Port-Orford-cedar' affects the properties of surface soils differently from conifers associated with it.

Little information is available (see Chapter 6) on volume growth and yield, particularly as these relate to levels of growing stock, stand composition and site quality.

Because silvicultural data are so limited and the root rot threat is so pressing, it seems reasonable that management guidelines for sustained cedar production should emphasize reducing the impact of disease.

Management to Minimize Effects of Root Rot

Strategy for control.—There are no available means for direct or chemical control of Port-Orford-cedar root rot, nor does cedar have a proven usable level of genetic resistance to ***Phytophthora.*** Port-Orford-cedar is so susceptible to ***P.*** lateralis that the tree cannot be grown in the presence of the fungus. The only strategy currently available for control is escape. The level of success depends mostly on the manager's ability to limit disease spread. Spread results largely from human activity, much of which is subject to regulation; however, spread by means of hooves of animals greatly complicates the task of growing trees that will escape the disease.

Management based on escape from disease is a long-term undertaking. Some young cedar may be cut, for fiber or other domestic use, concurrently with harvest of rotation-aged Douglas-fir sawtimber. Cedar appears unlikely, though, to attain high value for the export market in less than 200 years (at a minimum, two rotations of Douglas-fir). The fine grain and large size needed for export value require slow growth for long periods.

Root rot has become so conspicuous in the commercial forest that the thought of trees escaping infection today, much less for 200 years, may appear impossible. Several considerations suggest, however, that protecting trees by management is feasible: (1) the disease is sharply restricted by natural features of host, fungus, and habitat; (2) discontinuous distribution of the cedar precludes vegetative growth of the fungus uphill; (3) aerially transmitted spores are lacking; and (4) the spores are spread by water, which prevents the disease from moving rapidly up the slopes.

The manager's goal becomes one of growing cedar on sites that are unlikely to be reached by the root rot fungus. This requires minimizing activity by potential carriers of spores and moderating impact where activity is unavoidable. This is particularly important during conversion of the forest from an unmanaged to a managed state, which requires construction and disturbance that easily spreads the disease. The forest will stabilize upon final conversion and the rate of disease development will decline.

Suppression tactics involving individual components of the epidemic.— Specific suppression tactics are applicable to individual components of the cedar root rot epidemic (host, pathogen, and environment), and to physical and functional factors influencing the components. These various elements are inextricably interwoven and difficult to discuss in isolation.

Achieving safe siting and spacing.—Large populations of susceptible cedars, vulnerably situated, are the foundation of the cedar root rot epidemic. Phytophthora lateralis probably never would have emerged in epidemic form, if at all, without mass production of ornamental Charnaecyparis in northwestern Oregon and Washington and its widespread planting. Logically, whether in the native cedar range or elsewhere, the reverse procedure of reducing the cedar population should suppress the epidemic. The disease, of course, is already doing this, but this unplanned loss in the forest defeats the silvicultural objective of sustained high volume production of cedar. Accordingly, we are caught in a paradox in which the very trees we need are the heart of the problem.

In a direct way, a large population enhances an epidemic only in that large numbers of trees increase the proximity of individuals, so that probabilities of exposure to contagion are raised. A large number of infected trees provides a massive source of spores that indirectly may be as important to the epidemic as is the death of those trees. This is particularly true of trees too small for commercial use.

Both cedar and fungus are favored by moist habitats, so the cedar population is concentrated in the sites most vulnerable to infection. Because most of these sites are unlikely to escape contamination, the only alternative now available to the manager is to remove these cedars and replace them, where possible, with immune species (any other conifer suited to the particular site) that will suppress Port-Orford-cedar regeneration. Cedar production must be shifted onto the less vulnerable, convex, uphill slopes beyond the influence of drainages and roads. On fertile, convex slopes in the northern part of the range, cedar establishment and growth are excellent, but protection from suppression by Douglas-fir will be necessary where cedar production is shifted to these sites.

Where water is the only probable means of disease spread, the shift to higher ground need be no more than 15 m, and hillside stocking on safer sites can be increased to as high as 25 percent. Intervention by elk or other carriers is, unfortunately, quite possible at such locations; distances from drainages and between trees must be increased as game densities and livestock increase.

A shift of cedar production away from the wet areas is not an available alternative in the southern, drier, and inland parts of the range. There, a rigorous program is needed to protect existing stands. Such a program can be highly effective because stands are already widely dispersed and the prevailing general environment discourages movement of the fungus.

Limiting inoculum supply—Inoculum consists of waterborne zoospores and of resting spores formed in the forest litter and the organic fraction of the soil under diseased trees. At sites of high activity by potential carriers, resting spores incorporated into mud constitute the principal contagion. This mud, moved on hooves of animals and by vehicles and machines, accounts for broad distribution of root rot within the forest. Although swimming spores are widely produced from this contagious slurry and from living infected rootlets, and although they are the only infective agents, they become narrowly channeled by flowing water; their function in epidemic spread of root rot is limited except where water accumulates. The larger the area of infected trees on sites where water accumulates, the greater are the probabilities that carriers will enter the area, pick up, and spread the inoculum. Flood waters causing erosion are believed to move the long-lived resting spores so that alluvial gravels become contaminated and infectious. Quarry rock rather than river gravel should be used on roads.

The main objective of management, as it relates to inoculum, must be to limit or reduce the number, size, and accessibility of sites where transmitters can pick up the fungal spores.

Production of new sources of contamination can be reduced by prelogging cedar in vulnerable situations and using cleaned equipment. Operations must be based on overall long-term management objectives and the present root rot distribution. Agencies will need to classify all their cedar sites according to vulnerability to infection. Attention must be given both to position of the trees, including proximity to existing mortality, and to location and scheduling of work planned for each locality. The most exposed patches should be expeditiously and completely removed. Work should proceed to progressively less vulnerable stands. Cedar on convex slopes or above roads, or that are otherwise protected, should be retained for later harvest, even though heavy demand for Douglas-fir will generate considerable pressure to harvest these mixed stands prematurely.

This preventive harvest plan cannot be carried out using “business as usual” methods. Many units will be small and difficult to log; logging them will demand care and thoroughness. The units will include substantial cedar volume, however, and in most cases will be of sufficient value to justify considerable cost. Every small tree must be logged or killed. To limit cedar regeneration, logging should cause minimal disturbance of the forest floor, and alternative immune species (western hemlock, western redcedar, true firs, Douglas-fir, or hardwoods) should be protected and regenerated on the site at the highest possible densities. Prescribed fire might be used to remove unwanted cedar saplings. On some serpentine sites, protective vegetative cover may have to be entirely brush species, forbs, and grasses. To avoid introducing the fungus, all work should be done in the driest part of summer with machinery that has been thoroughly scrubbed free of dirt. Helicopter logging would be ideal and should be required where it would be cost effective.

Existing contaminated sites will remain a threat as long as they are allowed to regenerate to cedar. The severity of the threat is proportional to the amount of cedar present. Resources to treat such sites probably will be limited except where salvageable timber is present. An effort should be made to keep as many of these areas as possible completely free of cedar regrowth to allow time for the fungus to die. Contaminated sites near substantial, healthy cedar stands on elevated ground should be cleared of cedar and, where possible, fenced to exclude potential carriers. All contaminated sites should be posted with appropriate signs cautioning against thoughtless entry.

Working when the environment retards infection.—The forest environment of the Port-Orford-cedar region is favorable for *Phytophthora* lateralis most of the winter and never threatens the life of the fungus. In summer, the fungus either is sheltered from drought within living roots or is in the dormant spore form in the soil.

Fungal activity, as opposed to death, is greatly limited, though, by summer drought. Active spread of zoospores begins after soils become saturated in the autumn. Zoospores are readily detected in streams in late autumn and in winter after soil aquifers become charged, but during the summer the zoospores cannot be found in the streams and presumably are absent. Passive spread occurs naturally by chlamydospores only when soil is wet enough to adhere to animals or machines, or during floods. The primary effect of environment on the epidemic is to regulate periods favorable for sporulation, spread, and infection. Periods conducive to disease spread are longer in the north and towards the coast, where they combine with the greater abundance of cedar to aggravate the epidemic.

Forest operations on cedar sites must be conducted only when soils are dry enough that they will not stick to equipment. This may never occur in some wet locations, and rigid, alternative sanitary measures will be required. Duration of safe periods will vary with local weather, topographic location, and from place to place even during the safer summer months.

Regulating disease transmission.—Carriers of root rot spores are more easily controlled by management than are the other factors. The root rot fungus has been hauled around in excavation and earth work, in shipment of plants in infested soil, and in use of river gravel on roads. Spillage and drainage from these sources contaminate roadside ditches and streams. This contagion is perpetuated and increased as cedars become established and then infected in the frequently worked soil along the road and ditches. Survival of ***Phytophthora*** on any road surface probably is poor, but cleaning of ditches without concern for suitability of dump sites, and grading of the road surface or shoulders brings the fungus out of the ditches and spreads it. At times, most roadsides in the epidemic area are infectious. Front-end loaders, back-hoes, and other equipment that periodically work in the ditches are particularly active in spreading the fungus.

Roadside contagion contaminates logging machinery, trucks, and off-road recreational vehicles as they are unloaded, loaded, or cross the ditches. This equipment carries the fungus into the woods and broadly over the land. Trucks using newly graded rock roads and certainly dirt roads may become contaminated in wet weather and move the fungus for miles along the road. All of these inoculum sources drain to the lowlands to infect cedar along the streams or wherever water collects.

A first essential step for all areas where work is scheduled, and ultimately all areas where cedar is a consideration, is preparation of detailed maps that locate all Port-Orford-cedar timber and road segments, ditches, swamps, and streams that are infectious; this work is in progress for some USDA Forest Service lands. If these maps are kept current and are regularly consulted, planning and day-to-day management for sanitary operations will emanate from them. The maps can be checked, for example, to assure that infectious, dirty machinery, in the absence of pressure cleaning, is moved only to another infectious site, or away from cedar production areas.

Viable fungus should be absent from warm, dry (dusty) roads and probably would not survive long in moist soil dropped on such a road in summer. The same soil falling into a ditch or onto the forest floor could be dangerous. Consequently, machinery should be cleaned between jobs in summer as well as in winter. Inoculum on animals probably is not exposed to extreme heat or drought. Survival time on the leg of an animal could be fairly long in winter. This emphasizes the importance of excluding elk and cattle from infested swamps and meadows wherever possible. Abrasion of hooves during an animal's movement should remove contaminated mud within a few hundred meters. Cedar production, as well as unwanted cedar, should be kept away from areas of heavy animal use; likewise, free-ranging cattle should be excluded from areas being managed for cedar.

Appropriate planning of access to lands identified for cedar production should include:

1. Entering units by spur roads that can be abandoned, blocked, or gated after stand establishment.

2. Locating roads below units. High roads, where required, should be over the crest from the cedar production site to limit exposure of the site to infection and to direct drainage away from the site.

3. Engineering all roads to remove water as quickly as possible into unobstructed, natural waterways.

None of the disease-reducing practices applicable to the four components of the root rot epidemic can be carried out completely; however, progress on each will sufficiently supplement the others to result in much forest area that will remain free of root rot indefinitely.

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English Equivalents

	Metric	English
Length	1 millimeter 1 centimeter 1 meter 1 kilometer	0.0394 inch 0.3937 inches 39.37 inches, 3.28 feet 0.6214 miles
Area	1 square millimeter 1 square centimeter 1 square meter 1 hectare 1 square kilometer	0.001552 square inches 0.155 square inches 10.7639 square feet 2.4710 acres 0.3861 square miles
Volume	1 cubic meter 1 cubic centimeter	35.3145 cubic feet 0.0610 cubic inch
Weight	1 gram 1 kilogram	0.03527 ounces 2.2046 pounds
Pressure	1 bar	0.9869 atmosphere
Timber product volume (approx.)	1 cubic meter	176 board feet, 0.39 cord
Basal area per land area	1 square meter per hectare	4.33560 square feet per acre
Volume per area	1 cubic meter per hectare	0.1558 cords per acre, 71.457 board feet per acre[30] 14.2913 cubic feet per acre
Temperature	degrees Celsius	(degrees Fahrenheit - 32)/1.8

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[30] 1 cubic foot = 5 board feet

Source: Munns and others 1949.

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Appendix

Kellogg's description of Port-Orford-cedar as ***Cupressus fragrans,*** quoted below, contains apparently the earliest published information about the forests and their use (Kellogg 1857, p. 115-116). The latitudes cited are incorrect.

* * * * * * *

5 October 1857

San Francisco

Dr. Kellogg read the following paper, with appended remarks by Dr. Beardsley.

Dr. Kellogg exhibited a drawing and specimens of a new species of Cypress.

CUPRESSUS **FRAGRANS,** Kellogg; or the Fragrant Cypress.

Branchlets, four-sided, somewhat compressed, densely crowded, subdivisions numerous, with a frond-like arrangement; larger branches roundish, slightly compressed laterally, flexuose; ***bark*** madder brown; ***leaves*** diamond-acute and aculeate, shining, bright, vivid green, carinate, an oblong resinous gland along the back, appressed, imbricated in four rows; older leaves on the intermediate branches long, decurrent; point awl-shaped, incurved.

Cones pedicilate on long, scaly footstalks, similar to the branchlets, somewhat elongated, globose cinnamon color, size of a hazel-nut, composed of about nine peltate scales; center depressed; margin thickened and rounded; disk corrugated and rough, a sharp, transverse ridge divides it somewhat above the center; the mucro broad, thin or flat, pointed, fragile, curved outwards and pointed towards the apex; scales irregularly five-sided.

Seeds broadly winged all round, waved, oblique, scooped; base of the smooth cylindrical kernel portion prominent; apex emarginate, mucronate, bright cinnamon color.

This species bears the nearest resemblance to ***C. lawsoniana,*** but differs from it most strikingly in the brighter green of its foliage and its far denser branchlets; also in the leaves being narrower, much more angular, sharper pointed; the cones are from one-third to twice the size, more rough, also in color, form, and more sparse distribution, etc.; it is also a tree of larger proportions in all respects. The specific name chosen is intended to express its quality, par excellence. We know of no species **so** agreeably fragrant; the wood abounds in an oil which exhales a peculiar spicy aroma, in which the ginger odor predominates.

This notable odor has sometimes given it the common name of “Ginger Pine” among lumbermen. Some speak of it as “White Cedar”; in the market it is also known by the more indefinite name of “Oregon Cedar.” The grain of the wood is commonly a fine, close texture, strong and elastic; the annual concentric circles are often as large and distinct as the Eastern white pine (***P. strobus),*** showing it to be a tree capable of rapid growth. It has gained a good reputation among carpenters since it has been brought into market properly seasoned; it works easy, and burnishes smoother than the white pine.

We understand suitable machinery is now on the way to this city **(S.F.)** for the purpose of working this lumber into tubs, pails, and other domestic wares, similar to our Eastern “Cedar Coopers,” as that **class** of mechanics is styled, who work only this species of wood.

The well-known collector and enterprising discoverer of this and several other new species of the conifers—Mr. **A.F.** Beardsley—has furnished the following observations:

CUPRESSUS FRAGRANS.

Among the timber trees of the Pacific Coast, the White Cedar, as it is commonly called, of Southern Oregon, is among the most interesting for the beauty of its foliage and utility of its wood. It is found in almost every situation contiguous to the coast, and for several miles inland, but most abundant in moist ground and low hills kept moist by the density of the forest. It nearly fills sections of the extensive forests in the maritime districts of southern Oregon, latitude 52° to 44°. It is mingled with ***Abies Canadensis, Abies Douglasii, Abies Menziesii*** [western hemlock, Douglas-fir, and Sitka spruce], and a Silver Fir that I could not designate, it having neither fruit nor flower at the time (May 25th), resembling Pinus ***grandis*** of Douglass [grand fir]. The trees stand so thick that the light can hardly penetrate the evergreen foliage, and in their gloomy shades spring at every step Rhododendrons, Dwarf Bay, Vacciniums, bearing a delicious red berry, and other shrubs and plants. This tree grows straight, six feet in diameter, 150 feet in height, and nearly destitute of branches for 50 to 70 feet; but when found singly, its long, slender, pendulous branches are retained down nearly to the ground, making the general outline columnar, surmounted by an elongated pyramid. The bark on the young stocks is thin, but as they grow old becomes thick; furrowed, and of a soft, fibrous texture, not unlike that of ***Taxodium sempervirens*** [redwood], of a chocolate color. The color of the wood ,is white, rather heavier and firmer than white pine (Pinus strobus), which it much resembles; it is strong and durable, fine grain and easily wrought. It has a strong, fragrant, spicy odor, which it retains for a long time. This characteristic has suggested the name of Fragrant Cypress. The lumber made of it is of the best quality, being very clear from knots. It is extensively used in San Francisco for joiners' work, and commands the highest price in the market. It is preferred for clothes presses, chests, etc., having the same properties in this respect as camphor wood (*Laurus camphora*) in keeping away moths and other insects. It has been used in boat-building, and is highly recommended by those who have used it for this purpose. It would make excellent timbers in ship-building, where extra durability is required. There is no more valuable timber found on the Pacific Coast—the famous sugar pine (Pinus ***lambertiana***) not excepted. From the latitude in which it is found, it is unquestionably hardy, and its cultivation would be a valuable acquisition to the Atlantic States and Northern Europe.

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Zobel, Donald B.; Roth, Lewis F.; Hawk, Glenn M. Ecology, pathology, and management of Port-Orford-cedar *(Chamaecyparis lawsoniana).* Gen. Tech. Rep. PNW-184. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station; **1985.** 161 p.

Information about the biology, diseases, and management of Port-Orford-cedar was collected from the literature, from unpublished research data of the authors and the USDA Forest Service, conversations with personnel involved in all facets of Port-Orford-cedar management, and visits to stands throughout the range of the species. Information is summarized and presented regarding species characteristics, distribution, environment, vegetation, autecology, usage, past management, and the biology and effects of the most important pathogen. Recommendations for managing the species in the presence of this pathogen, *Phytophthora lateralis,* were developed. Presence of this introduced pathogen will complicate the management of Port-Orford-cedar and somewhat reduce the area where it can be grown, but production of future crops of cedar should be possible given careful, consistent application of the guidelines presented.

Keywords: Autecology, silvical characteristics, silviculture, root rot, ornamental trees, Port-Orford-cedar.

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