Chamaecyparis lawsoniana (A. Murr.) Parl. Port-Orford-Cedar

Cupressaceae Cypress family

Donald B. Zobel

Port-Orford-cedar *(Chamaecyparis lawsoniana),* also called Lawson cypress and Port Orford white-cedar, is known for its grace in ornamental plantings and for its versatile wood. As logs, mostly exported to Japan, it brings higher prices than almost any other conifer in the United States. This valuable tree, however, has a very limited range and an uncertain future. Management of Port-Orford-cedar has become impossible in much of its range since the introduction of a fatal root rot that is still spreading. Old-growth forests are being depleted rapidly, and the use of second-growth forests is complicated because early growth is relatively slow. The commercial future of one of the most beautiful and potentially useful trees will depend on development of silvicultural practices that-minimize infection by root rot.

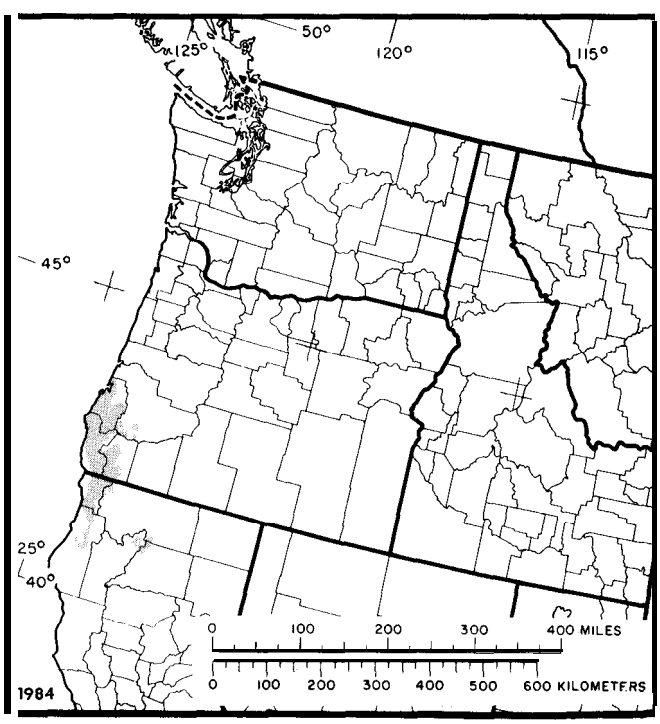

Figure *l-The native range of Port-Orford- cedar.*

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Habitat

Native Range

Port-Orford-cedar (fig. 1) grows in a small area near the Pacific coast, from about latitude 40" 50' to 43" 35' N. in southern Oregon and northern California *(13).* It is most important on uplifted marine terraces and in the Coast Ranges of southern Coos County and northern Curry County, OR. A secondary concentration is found at high elevations in the upper reaches of the Illinois and Klamath River drainages near the Oregon State boundary. Throughout the rest of its range, Port-Orford-cedar is found as small, scattered populations, most common in the drainages of the middle Rogue, upper Illinois, Smith, lower Klamath, and lower Trinity Rivers. A major inland disjunction includes small populations of the upper Trinity and Sacramento River drainages southwest of Mount Shasta, CA.

Climate

The Pacific Ocean strongly influences the climate of most of the range of Port-Orford-cedar. Winters are cool and wet; summers are warm and dry *(13).* Precipitation is moderate to high, usually 1000 to 2250 mm (39 to 89 in); only 2 to 4 percent occurs from June to August. A snowpack of 1 to 2 m (3 to 7 ft) is common at the higher elevations of the Klamath Mountains. Humidity remains high at night in most areas, although some interior valley sites have dry air during the day. Fog is common along the immediate coast and during the morning in some smaller interior valleys; summer cloudiness is most common near the northern end of the range. Temperatures varied widely in 2 years of measurement *(13).* At three coastal sites, monthly average understory air temperatures at 1 m (3 ft) ranged from 5" C (41" F) in January to 14° C (57° F) in July; the mean annual temperature was 8.5" C (47" F). At the warmest site at 360 m (1,180 ft) near Kerby, OR, monthly averages were 3" to 22" C (37° to 72" F) and annual average was 11.3" C (52" F); at the coldest site, southwest of Mount Shasta, CA, at 1520 m (4,980 ft), monthly averages were –2° to 14" C (29" to 57" F) and annual average was 5.2" C (41° F). The lowest air temperature measured in a Port-Orford-cedar stand was -15" C (5" F) at a height of 1 m (3 ft). Soil temperatures at 20 cm (8 in) below the surface were generally cool; the annual mean was 4" to 11" C (39" to 52" F). The

average difference between the warmest and coldest month was 8" C (14" F). Apparently the soils seldom freeze; the minimum temperature measured was -0.5" C (31" F).

Coastal winds in summer are primarily from north to northwest; they strike the coast at an angle at the north end of the range, driving moist air ashore and up the Coquille River Valley. This may influence the superb development of Port-Orford-cedar in this part of its range.

Soils and Topography

Port-Orford-cedar grows on many geologic and soil types: sand dunes; bogs, margins of intermittent streams, and drier sites on ultramafic rocks; and productive soils on sedimentary rocks and diorite ***(13).*** The largest trees are found on deep soils weathered from sedimentary rocks in Coos County, OR. The species is also found on sedimentary rocks near the lower Klamath River in California. Throughout much of its range, it is restricted to areas with consistent seepage within a meter of the soil surface. South of Coos County, OR, it is most common on wet spots on ultramafic rocks, especially at lower elevations in the inland and southern parts of its range. Reportedly, Port-Orford-cedar grows on soils in the orders Spodosols, Ultisols, and Inceptisols.

Soils vary from well developed, deep, and productive to skeletal (in seepage areas on peridotite) ***(13).*** Average depth to the surface of the C horizon ranges from 32 cm (13 in) in the mixed pine community to 73 cm (29 in) in the rhododendron community. Surface soils vary from sandy loam to clay in texture and often contain much gravel, cobble, or stone; their pH values range from 4.2 to 7.0; cation exchange capacities range from 10 to 42 meq/100 g. Concentrations of macronutrients are nitrogen, 0.12 to 0.25 percent; phosphorus, 2 to 40 p/m; extractable potassium, 36 to 400 p/m; extractable calcium, 0.3 to 10.8 meq/100 g; extractable magnesium, 0.2 to 9.9 meq/100 g. Calcium-to-magnesium ratios are 0.2 to 3.7. Foliar concentrations of nutrients in native saplings are often low (means for 85 saplings at 10 sites were 0.86 percent nitrogen, 0.52 percent potassium, and 0.11 percent phosphorus); in contrast, calcium is usually quite high (1.11 percent) ***(13).*** The calcium-to-magnesium ratio of foliage is high, averaging 4.4 and staying above 2 even on ultramafic substrates. Surface soils under Port-Orford-cedar plantations in Great Britain have the highest pH of soils under any conifer tested. Growth in the northern end of the natural range increases with levels of nitrate in the soil. In culture, growth increases with levels of potassium, nitrogen, and calcium in the foliage ***(13).***

In some areas in the northern part of its range, Port-Orford-cedar grows in habitats similar to those of western redcedar *(8,9)*. On sites where both species are present, soils under Port-Orford-cedar are usually more acidic and have higher concentrations of potassium and lower calcium:magnesium ratios. Mineralization of nitrogen is slower in Port-Orford-cedar litter.

Port-Orford-cedar usually grows on concave or sheltered slopes where soil seepage occurs ***(13).*** It is most common on slopes, on benches, and in drainageways. Restriction to streamsides and ravines is most obvious inland at low elevations. Stands are most common on northwest, north, and northeast aspects, especially at lower elevations. Port-Orford-cedar grows from just above sea level to about 1500 m (4,900 ft) in the main section of the range, and to 1950 m (6,400 ft) near Mount Shasta ***(13).***

Associated Forest Cover

Port-Orford-cedar is found with an extremely wide variety of associated plants and vegetation types. It usually grows in mixed stands and is important in the ***Picea sitchensis, Tsuga heterophylla,*** mixed evergreen, and ***Abies concolor*** vegetation zones of Oregon *(3,13)* and their counterparts in California ***(1).*** It also grows in a variety of minor communities from dry sand dunes to *Darlingtonia* (cobra-lily) bogs. The species reaches its greatest size and commercial worth in the dense, rapidly growing forests of the ***Picea sitchensis*** and the ***Tsuga heterophylla*** zones (fig. 2), in which Douglas-fir often dominates. Port-Orford-cedar is most dominant on wet soils, most of which have parent material at least partially ultramafic, in the high elevation ***Abies concolor*** zone where forests are dense but slow growing ***(13).*** In the mixed evergreen zone, it is the only shade-tolerant conifer in most stands. On drier sites on ultramafics and in bogs, forests can be very open and slow growing. The cedar is dominant in the forest cover type Port-Orford-Cedar (Society of American Foresters Type 231) (2) and is listed as a minor associate for parts of the following types: Sitka Spruce (Type 223), Pacific Douglas-Fir (Type 229), Redwood (Type 232), Oregon White Oak (Type 233), and Douglas-Fir–Tanoak-Pacific Madrone (Type 234).

Major communities in old-growth forests where Port-Or-ford-cedar is a major component include the following, named for the apparent dominants at climax (abbreviated names are given in parentheses) ***(13):***

***Tsuga heterophylla* zone**

Tsuga heterophylla–Chamaecyparis lawsoniana* / *Polystichum munitum–Oxalis oregana (swordfern); ***Tsuga heterophylla–Chamaecyparis lawsoniana /Rhododendron macrophyllum-Gaultheria shallon*** (rhododendron); ***Chamaecyparis lawsoniana-Tsuga heterophylla /Xerophyllum tenax*** (bear grass).

Figure 2—*Old-growth* Port-Orford-cedar forest on productive soil developed from sedimentary rocks, on a bench in the Coquille River Falls Research Natural Area, Coos County, OR.

Mixed evergreen zone

Chamaecyparis lawsoniana* /*Lithocarpus densiflorus (tanoak); ***Pinus–Chamaecyparis lawsonina* / *Quercus vaccinifolia* /*Xerophyllum tenax*** (mixed pine).

Abies concolor zone

Abies concolor–Tsuga heterophylla–Chamaecyparis lawsoniana (white fir-western hemlock); ***Abies concolor–Chamaecyparis lawsoniana I*** herb (white fir); ***Abies-Chamaecyparis lawsoniana*** /herb (mixed fir).

Port-Orford-cedar is less common in a wider variety of forest communities.

Plants of major importance associated with Port-Or-ford-cedar vary among zones *(6,13)*. ***Trees*** are Sitka spruce *(Picea* ***sitchensis),*** western hemlock ***(Tsuga heterophylla),*** Douglas-fir ***(Pseudotsuga menziesii),*** tanoak ***(Lithocarpus densiflorus)***, sugar pine *(Pinus* ***lambertiana),*** Jeffrey pine *(P.* ***jeffreyi),*** western white pine *(P.* ***monticola),*** redwood ***(Sequoia sempervirens),*** white fir ***(Abies concolor),*** and Shasta fir (A. *magnifica* var. ***shastensis).***

Shrubs are Pacific rhododendron ***(Rhododendron macrophyllum),*** western azalea *(R.* ***occidentale),*** evergreen huckleberry *(Vaccinium* ***ovatum),*** red huckleberry *(V.* ***parvifolium),*** salmonberry *(Rubus* ***spectabilis),*** cascara buckthorn *(Rhamnus purshiana),* California buckthorn *(R.* ***californica),*** salal ***(Gaultheria shallon),*** Pacific bayberry *(Myrica* ***californica),*** huckleberry oak ***(Quercus vaccinifolia),*** Sadler oak *(Q.* ***sadleriana),*** western leucothoe ***(Leucothoe davisiae),*** Pacific ***yew*** *(Taxus* ***brevifolia),*** Oregongrape ***(Berberis nervosa),*** and Oregon boxwood ***(Pachistima myrsinites).***

Important herbs are swordfern ***(Polystichum munitum),*** Oregon oxalis *(Oxalis* ***oregana),*** beargrass *(Xerophyllum tenax)*, western twinflower *(Linnaea* ***borealis*** var. *longiflora)*, vanillaleaf *(Achlys triphylla),* prince%-pine *(Chimaphila* ***umbellata*** var. *occidentalis),* Hooker fairybells ***(Disporum hookeri),*** western starflower *(Trientalis* ***latifolia),*** and inside-out-flower *(Vancouveria* spp.).

The general relationships of well-developed Port-Orford-cedar forests to rock type, geographic location, and elevation are shown in figure 3. These forests have 75- to 86-percent cover by trees more than 15 cm (6 in) in d.b.h., except the mixed pine community, which has 39 percent. Tree reproduction is often abundant, and density of trees less than 15 cm (6 in) in d.b.h. ranges from 1246/ha (rhododendron community) to 4113/ha (white fir) (504 to 1,664/acre); 26 percent (swordfern) to 78 percent (tanoak) of these are Port-Orford-cedar; cover of tree reproduction ranges from *30* to 46 percent.

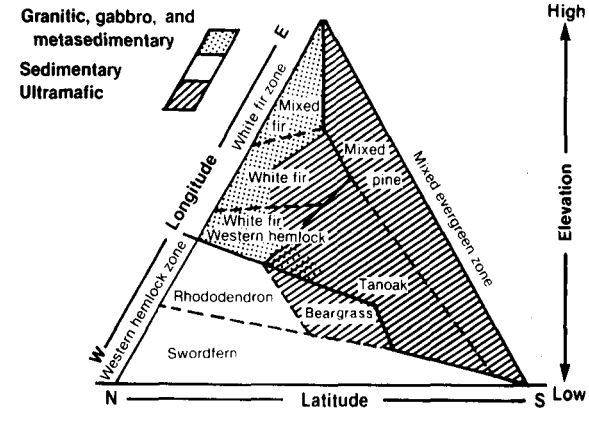

Figure &*Distribution of vegetation zones and eight major forest communities of old-growth Port-Orford-cedar, in relation to soil parent material, elevation, and geographic location. Zones are separated by solid lines, communities by broken lines (modified from 6).*

Shrub cover is very dense in rhododendron and tanoak communities (over 90 percent), moderate to dense in most communities (30 to 67 percent), but only 9 percent in the swordfern community. Moss cover is high in the *Tsuga* zone.

Representation of Port-Orford-cedar is usually lower in the forest than in the cedar-dominated communities described above (13). For example, on 3752 ha (9,271 acres) of the former Port Or-ford Cedar Experimental Forest in southern Coos County, OR, 28 percent of total timber volume was Port-Orford-cedar. Cedar volume exceeded 50 percent on 41 percent of the area, was 25 to 50 percent on 7 percent of the area, 10 to 24 percent on 15 percent of the area, and less than 10 percent on the remainder.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Pollen and seed cones develop on the same branches of this monoecious species. Reproductive organs are initiated in late spring or summer. They soon protrude beyond the surrounding leaves, and development continues through the summer. The bladderless pollen is formed in late winter in the bright red pollen cones; on the Oregon coast it is shed about mid-March. Fertilization occurs a month or more later, and seeds mature in September or October of the same season *(5,13)*. Each fertile scale of the 7 to 10 scales in the globose cone usually bears 2 to 4 seeds. Cones contain about 20 percent of their weight in seeds (5).

Seed Production and Dissemination-Seed production starts when the tree is 5 to 20 years old (5). It can be induced in trees as young as 7 months with sprays of 50 p/m gibberellic acid (the effect is enhanced by Ethrel) with the correct photoperiodic regime ***(13).*** (At least 2 weeks of long days are required after gibberellin treatment, followed by at least 2 weeks of short days, followed by long days to allow cone maturation.)

The major peak of seedfall is in the late fall, with a smaller one in spring. Roughly 50 to 60 percent of the seeds fall by mid-January and 85 to 90 percent by May 1 ***(13);*** however, some seed is released all year.

Crops of 20,000 to 4,600,000 seeds per hectare (8,094 to 1,862,000/acre) have been measured, with a mean of 829,000 seeds per hectare (335,000/acre) for 30 crops ***(13).*** Annual seed production can also be expressed in relation to a unit basal area of the population; 600 to 185,000 with a mean of 40,200 seeds per square meter (56 to 17,187 with a mean of 3,735/ft^2) of basal area were produced. Of 30 crops, 5 exceeded 100,000 seeds per square meter (9,290/ft^2) of basal area, 6 produced 20,000 to 60,000 seeds per square meter (1,858 to 5,574/ft^2), 6 had 10,000 to 20,000 seeds per square meter (929 to 1,858/ft^2), and 13, less than 10,000 seeds per square meter (929/ft^2). High seed production per unit basal area occurred in all types of habitats sampled and in both 65-year-old and old-growth forests. No site had good or moderate seed crops 2 years in succession. There seems to be no regional synchronization of large seed crops, however, as occurs in many tree species.

The seeds are small, averaging about 463 000/kg (210,000/lb), with a range of 176 to 1323/g (80,000 to 600,000/lb) (5). Despite having small wings along both sides, the seeds apparently fall more rapidly than many larger conifer seeds. The seed wings appear to aid their flotation on water. Seeds are not a preferred food of rodents in feeding experiments *(7)*, but harvesting of large numbers of cones and removal of seed from them by rodents have been observed in natural stands ***(13).***

Seeds may be stored frozen at less than lo-percent moisture in a sealed container for more than 10 years and retain considerable viability *(5,12)*. One study reports 43-percent germination from seed stored this way for 13 years. Few seeds, if any, germinate later than the first year after dispersal ***(13).***

Seedling Development-Seed germination is epigeal; in the natural habitat, it occurred in early June or later in the 1 year it was observed ***(13).*** Germination ranged from 11 to 44 percent in natural seed fall trapped on the floor of seven forests. Germination of collected seed is often higher, about 50 percent (5).

Stratification increases germination and seedling growth for some seed lots ***(13).*** Red light accelerates germination; far-red light delays it. In laboratory conditions, few seeds germinate below 12" C *(12)*. Sowing in the nursery in March and April is more reliable in England than fall sowing ***(13).*** In nursery practice, seeds were sown at 320 to 540/m^2 (30 to 50/ft^2) and covered by 3 to 6 mm (0.12 to 0.25 in) of soil (5). Shading until midseason may be helpful. A nursery yield of 284,000 usable plants per kilogram of seed (129,000/lb) has been reported (5). Port-Orford-cedar seedlings are easy to grow and establish ***(13).*** Seedlings have been planted as 2-O or 3-O stock in the United States, and after the first or second year, or as 2-1 stock in Great Britain. Spacing in Britain is 1.4 to 1.5 m (4.5 to 5 ft); recently, in its native range, Port-Orford-cedar has been interplanted with Douglas-fir, at 2.7- to 8-m (9- to 26-R) spacing *(13)*.

Seedlings are small, with two cotyledons. The next several whorls of leaves are needlelike (5 to 13 whorls in one study); successive whorls gradually develop into the mature, appressed, scalelike foliage differentiated into the flat "facial" and the folded "lateral" leaves *(13).* Seedling establishment in small experimental plots under a natural canopy was most common where soil had been disturbed but did occur in natural litter; after three growing seasons, only 5 percent of the germinants survived in the most favorable soil conditions. In clearcut or partially cut areas, establishment decreases as ground cover vegetation increases *(7).*

Seedling growth under a canopy is slow-experimental seedlings are only about 40 mm (1.6 in) tall after their second growing season *(13).* Seedlings in the open average 36 mm (1.4 in) after 1 year and 78 mm (3.1 in) after 2. Planted 3-O stock averaged 48 cm (18.8 in) tall after 2 years in the field *(7).* Natural seedlings established under a canopy take 14 to 31 years to reach breast height (1.37 m; 4.5 ft), compared with 5 to 11 years for trees in clearcuts on nonultramafic soils *(13).* Early seedling growth sometimes equals that of Douglas-fir in the same clearcut. Seedlings are quite shade-tolerant but do die in dense shade under old-growth forest and do not become established under young, dense, even-aged stands *(13).* They seem to survive in most understory microsites where western hemlock and white fir can grow.

Port-Orford-cedar often reproduces aggressively from seed. Natural reproduction in clear-cuts is usually adequate within 80 to 110 m (262 to 361 ft) of a seed source; however, planting will often be required in large clear-cuts *(13).* Planted seedlings may grow normally in dense competition from gorse or bracken fern. Later growth is intrinsically somewhat slower than that of Douglas-fir *(13),* and weeding may be necessary to keep Port-Or-ford-cedar in the upper canopy where maximum growth is possible.

Port-Orford-cedar does not develop winter buds with preformed internodes *(13).* Elongation continues for as long as 5 months in mild coastal climates; it is more rapid and early in the mixed evergreen zone and equally rapid but late in the *Abies concolor* zone. Elongation lasts 1.3 to 1.9 times as long as that of Pinaceae on the same site.

Vegetative Reproduction-Cuttings may be rooted with relative ease *(13).* A recommended practice is to use cuttings from tips of major branches from the lower crown of young trees, taken from December to February Auxin treatments sometimes aid rooting. Natural layering of Port-Or-ford-cedar occurs occasionally *(13).* Several vertical limbs of windthrown trees in open stands may develop into separate trunks attached to the horizontal "parent" trunk. Most reproduction, however, is from seed.

Sapling and Pole Stages to Maturity

Growth and Yield-After the sapling stage, growth of Port-Or-ford-cedar is considerably slower than that of Douglas-fir, except on ultramafic substrates where the cedar is usually exceeded in size only by sugar pine *(13).* In 8- to 26-year-old plantations in the Pacific Northwest, annual height growth of unbrowsed Port-Orford-cedar averaged 0.35 m (1.15 ft), only 86 percent of the mean annual height growth of Douglas-fir; the difference was much greater for browsed trees. In mixed stands, Port-Or-ford-cedar is usually overtopped by 20 to 25 years. Pole-size stands in the northern part of the range show a large difference in both diameter and height between Douglas-fir and cedar. In one small sample of 53- to 60-year-old trees (age determined at breast height) in coastal Coos County, OR, the Douglas-fir averaged 73 cm (29 in) in d.b.h. and 38 m (125 ft) in height; the cedar averaged 47 cm (19 in) and 28 m (92 ft). Measurements of adjacent stumps on several sites throughout the range showed that the diameter of Port-Or-ford-cedar was 57 percent that of Douglas-fir at 100 years; however, the difference decreased with age, cedar becoming 74 percent of the diameter of Douglas-fir at 200 years, 78 percent at 300, and 90 percent at 400 *(13).* Diameter growth of cedar is thus more consistent throughout its life than is that of Douglas-fir.

Size of old-growth cedar trees is variable; much variation is associated with the habitat (and thus the forest community) *(13).* Early rapid height growth in open stands on ultramafic rocks is not sustained. For example, a sample of forest-grown 90- to 110-year-old trees averaged 30 m (98 ft) in height in the swordfern community, 18 m (59 ft) in the mixed pine community on ultramafics, and 12 to 13 m (39 to 43 ft) in other communities. By 190 to 210 years, heights were 47 m (154 ft) for swordfern, 25 to 29 m (82 to 95 ft) for other communities, but only 21 m (69 ft) for the mixed pine community. At 290 to 310 years, values were 63, 31 to 50, and 29 m, respectively (207, 102 to 164, and 95 ft). Average diameters in old-growth stands range from 42 cm (17 in) (diameter of a tree of mean basal area, mixed pine community) to 86 cm (34 in) (swordfern). Trees more than 100 cm (39 in) in d.b.h. occur in many old-growth stands, and trees of 200 to 250 years may reach 100 cm, but most trees this size are older than 300. On the other hand, one 37-cm (15-in) tree in the mixed pine community

Table l-Attributes of British plantations of Port-brford-cedar and western redcedar for the least productive (A) and most productive (B) yield classes[1]

Stand	Trees		Height		Diameter		Basal area maintained after thinning		Cumulative yield	
age	A	B	A	B	A	B	A	B	A	B
yr	*no./ha*		*m*		cm		*d/ha*		*m³/ha*	
20	3,575	2,186	8	13	10	14	28	35	50	232
40	1,730	746	16	24	18	30	42	54	377	901
60	984	451	21	30	26	43	51	66	706	1,439
80	738	347	24	35	32	53	59	76	953	1,838
yr	*no./acre*		*ft*		*in*		*ft²/acre*		*ft³/acre*	
20	1,447	885	26	43	3.9	5.5	122	152	715	3,315
40	700	302	52	79	7.1	11.8	183	235	5,388	12,876
60	398	183	69	98	10.2	16.9	222	287	10,090	20,565
80	299	140	79	115	12.6	20.9	257	331	13,620	26,267

[1] Yield classes A and B support maximum mean annual increments of 12.0 and 24.0 m^3/ha (171.5 and 343.0 ft^3/acre), respectively. Yields include thinnings and are computed for top diameter of 7 cm (2.8 in) outside bark (adapted from *13*).

was more than 300 years old. Maximum tree age exceeds 560 years ***(13).***

Relatively few yield values exist for young stands. Experience in Great Britain is limited but well documented ***(13);*** Port-Orford-cedar is combined with western redcedar in yield tables (table 1). Thinnings begin at 20 to 30 years. Mean annual increment (MAI) peaks at 57 to 72 years. Current annual increment (CAI) increases later than for Douglas-fir and western hemlock on good sites and after its peak decreases more slowly than Douglas-fir but faster than hemlock. On poor sites, CAI starts to increase late than for Douglas-fir but earlier than for hemlock; it decreases after Douglas-fir but before hemlock. On good sites, peak MAI is reached 5 years later than for Douglas-fir and hemlock; on poor sites, it is reached 10 years later than for Douglas-fir but 5 years earlier than for hemlock. In one study, cedar plantations at 60 years were maintained at two to three times the density of Douglas-fir with 1.4 to 1.5 times higher basal area. Sixty-year-old trees averaged 5 to 8 m (16 to 25 ft) shorter and 11 to 20 cm (4 to 8 in) smaller in diameter breast height than Douglas-fir.

Volumes reported from young natural stands in Oregon (table 2) and plantations in Europe and New Zealand *(13)* are in the moderate to low range, compared with British plantations; however, the small top diameter limit used for table 1 and the impurity of natural stands may account for most or all of the difference. Values of MA1 for two Oregon stands (table 2) were 13.7 (61 years) and 16.9 m^3/ha (57 years) (196 and 242 ft^3/acre).

Live volumes of Port-Orford-cedar in old-growth forest sampled in 1935-40 averaged 86 m^3/ha (1,229 ft^3/acre) in the valley of the South Fork of the Coquille River (Port Orford Cedar Experimental Forest, 3752 ha or 9,271 acres); the most volume in a 259-ha (640-acre) section was 154 m^3/ha (2,201 ft^3/acre) ***(13).*** Average volume near Bluff Creek, southwest of Orleans, CA, in 1940 was 22 m^3/ha (314 ft^3/acre) and the maximum was 47 m^3/ha (672 ft^3/acre) on 4922 hectares (12,162 acres>. Most volume was in large trees. On coastal terraces, the proportion of Port-Orford-cedar decreased as total volume of old-growth timber increased ***(13).***

Rooting Habit-A dense, coastal 50-year-old stand of Port-Or-ford-cedar on a clay-loam soil had a dense network of fibrous roots at the surface (4). The major horizontal system of surface roots extended up to 7 m (22 ft) from the trunk, producing "humus strivers" (roots with unlignified tips that rise into the surface soil and duff) uniformly along its length. Root systems of adjacent trees intermingled freely; some overlap was likely in trees closer than 12 m (39 ft). Root grafting was common in the main horizontal surface root system, averaging 1.5 grafts per tree; the average graft was 34 cm (13 in) deep between roots 3.8 cm (1.5 in) in diameter. The chance of grafting decreased with both horizontal distance between trees (becoming very small beyond 6 m (20 ft)) and with vertical distance on the slope; however, graft complexes that included several trees sometimes joined trees as far as 12 m (39 ft) apart. Port-Orford-cedar has no taproot but produces vertical sinkers from the horizontal system.

Port-Orford-cedar forms endomycorrhizae with fungi of the family Endogonaceae ***(13).***

Reaction to Competition-Port-Orford-cedar is tolerant of shade and of competition in natural

Table 2—Yields from young natural stands of Port-Orford-cedar in western Oregon (7)

Location	Stand age	Total stand all species		Port-Orford-cedar				
		Trees	Basal area	Trees	Basal area	Average diameter	Average height[1]	Volume
	yr	*no./ha*	*d/ha*	*no./ha*	*m^2/ha*	*cm*	*m*	*m^3/ha*
Coos County Forest	36	3,361	68	2,026	41	16	16	244
Coos County Forest	40	2,817	72	1,359	36	18	16	205
Coos-Curry county line	44	1,853	94	1,507	66	24	22	506
Coos-Curry county line	43	1,705	80	1,384	51	22	22	445
Port Otford	61	1,680	113	1,458	90	28	23	838
Port Orford	57	1,666	126	1,483	115	31	22	966
	yr	*no./acre*	*ft^2/acre*	*no./acre*	*ft^2/acre*	*in*	*ft*	*ft^3/acre*
Coos County Forest	36	1,360	298	820	179	6.3	51	3,490
Coos County Forest	40	1,140	312	550	157	7.2	52	2,930
Coos-Curry county line	44	750	408	610	287	9.3	73	7,230
Coos-Curry county line	43	690	348	560	222	8.5	72	6,360
Port Orford	61	680	490	590	393	11.1	74	11,980
Port Otford	57	670	548	600	503	12.4	73	13,800

[1]Height of trees of mean basal area.

stands *(13).* Its slow growth beyond the sapling stage results in its being overtopped, but it continues to grow and retains into old age the ability to respond after the dominants die *(7).* Port-Orford-cedar can reproduce effectively from seed after clearcutting and partial cutting (where a sufficient seed source is present) and under almost all natural forests, and it can be used for under-planting established forest or scrub *(13).* Some old-growth forest structures resulted from repeated waves of invasion, almost certainly after fires.

Because of its shade tolerance, relatively thick bark, high value, and moderate but consistent growth rate, Port-Or-ford-cedar might be grown effectively in a partial-cut system in which faster growing associates are removed part way through the rotation. Its litter (with high calcium and high pH) increases soil pH, suggesting that the species may be important in afforestation of moderately acidic soils or for ameliorating the effects of other conifers on soils (13).

Shade tolerance and a narrow crown allow dense stocking in British plantations, and volume for a given height is high *(13).* Holes left after thinning close slowly, however, and a longer thinning cycle is necessary than for most conifers. Pruning is not useful. Forking of trees has been a problem in many British plantations.

In recent years, plantations of Port-Orford-cedar have not been widely established in the Pacific Northwest outside its native range because of problems with root rot, winter damage, and its slow growth relative to other species *(13).*

Damaging Agents-The major causes of damage to Port-Orford-cedar are fungi of the genus *Phytophthora (11,131.* An exotic root rot caused by *P. lateralis* was introduced into Coos County about 1952 and has decimated many stands in the area where Port-Orford-cedar grows best. Neither resistance to the rot nor effective treatment of it has been identified. Spores of the fungus are carried by water, so one introduction of the disease may spread to all stands in the watershed below. Natural uphill spread is slow. Infections are carried uphill rapidly or between watersheds in mud on equipment or livestock, they have reached northern Del Norte County, CA. Many isolated stands or those uphill from infection centers, however, may be kept free of the disease by careful exclusion of contaminated machinery, livestock, and nursery stock.

Phytophthora cinnamomi causes major losses to some nurseries and cultivated trees. A white pocket top rot, caused by an unidentified fungus, is a serious problem. Losses to other diseases and to insects are minor *(13).* Animal damage to planted seedlings is highly variable, sometimes more and sometimes less than on associated conifers *(13).*

Drought damages native trees on the hotter sites and in inland areas without seepage *(13).* Port-Orford-cedar is more affected than its associates on these sites. Laboratory experiments show that it is also more susceptible to freezing than most as-

sociated trees, although reports of winter damage in the field vary ***(13).*** In some instances, no damage occurred at -25" C (-13" F); others report severe damage at -13" C (9" F). Most drastic winter kill occurred in dry, windy, cold weather, desiccation apparently being of considerable consequence. Susceptibility to spring frosts in Great Britain is lower for Port-Orford-cedar than for most of its usual associates. Damage by wind, ice, and snow occurs, but the species does not seem especially susceptible *(13).*

Port-Orford-cedar effectively recovers from loss of its leader or from extensive killing of foliage at the crown surface. If twigs are killed deeply enough into the crown, however, a tree apparently does not recover because it does not resprout from the "old ***wood)) (13).***

Port-Orford-cedar resists moderate air pollution but does poorly where pollution is intense ***(13).*** It is more sensitive to nitrous oxide than nitric oxide. Levels of sulfur dioxide that reduce photosynthesis of Port-Or-ford-cedar have little effect on Douglas-fir and western redcedar.

Although young trees are easily killed by fire, older trees develop thick bark and survive large, deep fire scars *(13).* In old stands, Port-or-ford-cedar seems as tolerant of fire as Douglas-fir.

Special Uses

Outside its natural range, the major use of Port-Orford-cedar is as an ornamental ***(13).*** As such, it is usually referred to as Lawson cypress. More than 200 cultivars are known, varying in size, shape, foliar morphology, and color. It is suitable for hedges but is usually planted as separate individuals of either full-sized or dwarfed varieties. Its use has declined in some areas because of root rot. Cut branches are used in floral arrangements.

Genetics

Population Differences

Port-Orford-cedar is extremely variable morphologically. Most horticultural cultivars originated as seedling mutations, produced by descendants of apparently only a few introductions to Great Britain ***(13).*** Some cultivars are notably more resistant to winter damage and spring frosts than are most, and some root more easily than others.

There is obvious variation in growth rates among seedlings and rooted cuttings from various natural populations; northern coastal sources grow faster than those from inland, and those from productive, dense forest types grow faster than those from open forests on poor soils ***(13).*** Relative growth rates of different populations remain the same in culture on both good and poor soils. In culture, differences in nutrient content, and stomata1 distribution occur among inland and coastal sources, and the foliar calcium-to-magnesium ratio is lower for a source from an ultramafic area than for those from other soils ***(13).*** Local variation occurs in stomata1 resistance of seedlings to water loss, but it is not consistent regionally.

Variability in adaptation of individual trees has been noted in Europe. Selections of desirable trees have been made in Great Britain. Apparently no provenance studies of growth have ever been made in field conditions ***(13).*** Trials of the species as an exotic may have suffered from the use of a limited seed source; the original introduction to Britain was from the upper Sacramento River, probably an area of slow growth.

Allozyme variability differentiated two inland populations from seven coastal populations in California. The disjunct inland populations contained less variability than the coastal samples. Considerable variation among populations existed in both inland and coastal regions *(10).*

Hybrids

Putative hybrids with ***Chamaecyparis nootkatensis*** have been identified in cultivation and in a natural sympatric stand ***(13);*** apparently none have been confirmed, however.

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