Tsuga heterophylla (Raf .) Sarg. Western Hemlock

Pinaceae Pine family

E. C. Packee

Western hemlock *(Tsuga heterophylla),* also called Pacific hemlock and west coast hemlock, thrives in humid areas of the Pacific coast and northern Rocky Mountains. Its potential for management as an efficient producer of fiber has long been recognized. It is an important browse species for deer and elk. Western hemlock provides an important part of the esthetic background for eight national parks-four each in the United States and Canada. It is a pioneer on many sites, yet it is commonly the climax dominant. Although western hemlock grows like a weed, its versatility and potential for management make it the “Cinderella of the Northwest.”

Habitat

Native Range

Western hemlock (fig. 1) is an important commercial tree species of the Pacific coast and northern Rocky Mountains. Along the Pacific coast, its range extends north along the Coast Ranges from central California to the Kenai Peninsula in Alaska, a distance of *3200* km *(2,000* mi) *(11,18,33).* It is the dominant species in British Columbia and Alaska along the Coast Mountains and on the coastal islands.

Inland it grows along the western and upper eastern slopes of the Cascade Range in Oregon and Washington and the west side of the Continental Divide of the northern Rocky Mountains in Montana and Idaho north to Prince George, BC *(7,18,26).*

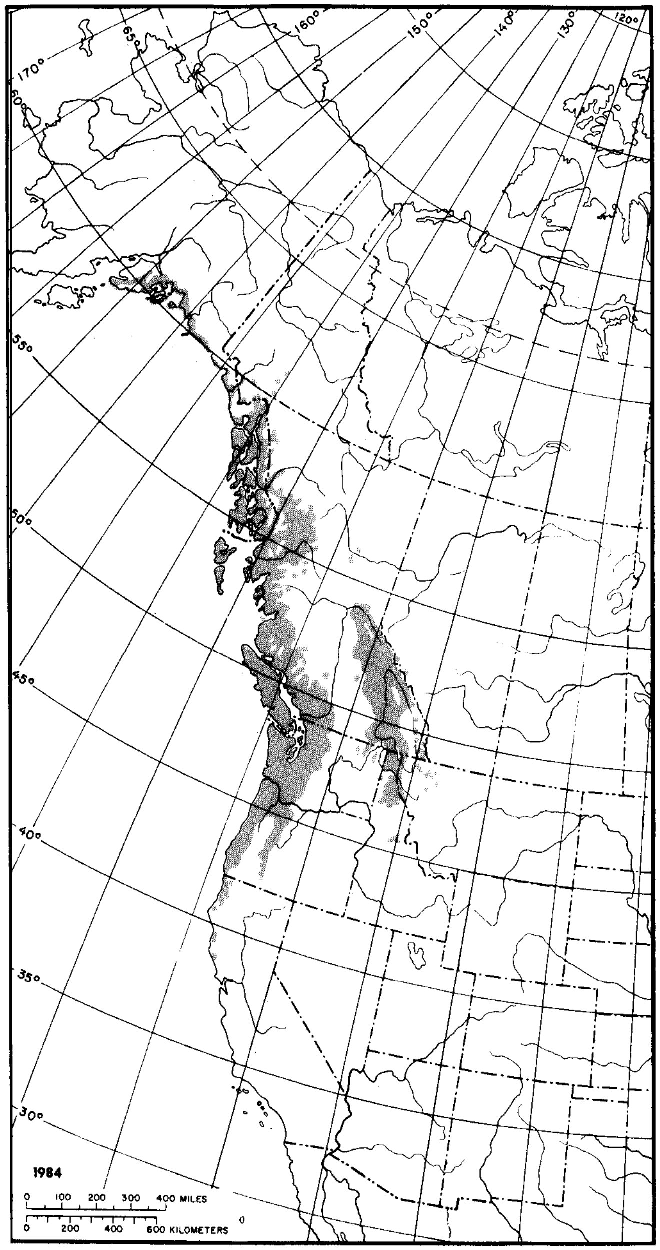

Figure 1—*The* native ***range of western hemlock.***

Climate

Western hemlock thrives in a mild, humid climate where frequent fog and precipitation occur during the growing season. Best stands are in the humid and superhumid coastal regions. In subhumid regions with relatively dry growing seasons, western hemlock is confined primarily to northerly aspects, moist stream bottoms, or seepage sites.

Within the coastal range of western hemlock, mean annual total precipitation ranges from less than 380 mm (15 in) in Alaska to at least 6650 mm (262 in) in British Columbia. The range in the Rocky Mountains is 560 mm (22 in) to at least 1730 mm (68 in) *(25).*

Mean annual temperatures range from 0.3” to 11.3” C (32.5” to 52.3” F) on the coast and 2.2” to 8.2” C (36.0” to 46.8” F) in the Rocky Mountains. Observed mean July temperatures lie between 11.3”

The author is Assistant Professor of Forest Management, University of Alaska, School of Agriculture and Land Resources Management, Fairbanks, AK.

and 19.7” C (52.3” and 67.5” F) along the coast and 14.4” and 20.6” C (58.0” and 69.0” F) in the interior. Mean January temperatures reported for the two areas range from -10.9” to 8.5” C (12.4” to 47.3” F) and -11.1” to -2.4” C (12.0” to 27.6” F), respectively. Recorded absolute maximum temperature for the coast is 40.6” C (105.0” F) and for the Rocky Mountains, 42.2” C (108.0” F). Absolute minimum temperatures tolerated by western hemlock are -38.9” C (-38.0” F) for the coast and -47.8” C (-54.0” F) for the interior.

The frost-free period within the coastal range of western hemlock averages less than 100 to more than 280 days (25). In the Rocky Mountains, the frost-free period is 100 to 150 days (20).

Soils and Topography

Western hemlock grows on soils derived from all bedrock types (except possibly serpentines) within its range. It grows well on sedimentary (argillites, shales, sandstones, limestones), metamorphic (gneisses, marbles, quartzites, schists), and igneous (andesites, basalts, diorites, gabbros, granites) materials. Under appropriate climatic conditions, it thrives on all major landforms-colluvial, eolian, fluvial, lacustrine, marine, morainal, residual, rock, and organic.

Western hemlock grows on a variety of soils and is a characteristic species on soils of 6 of the 10 soil orders: Alfisols, Entisols, Histosols, Inceptisols, Spodosols, and Ultisols; and on many great groups, including: Fragiboralfs, Fragiudalfs, Hapludalfs; Fluvaquents, Udifluvents, Quartzipsamments; Borofolists, Cryolfolists; Cryandepts, Dystrandepts, Vitrandepts, Cryaquepts, Haplaquepts, Dystrochrepts, Cryumbrepts, Haplumbrepts; Fragiaquods, Placohumods, Crvorthods, Fragiorthods, Haplorthods; and Haplohumults. ‘It is found on ‘most soil textural classes. Height growth, however, decreases with increasing clay content or soil bulk density. This is attributed to inadequate soil aeration (35) or the inability of roots to penetrate compact soils.

Western hemlock thrives on soils with perudic and udic soil moisture regimes. If, however, internal soil drainage is restricted within 1 m (3.3 ft) of the soil surface, height growth decreases (35). Western hemlock is poorly suited to sites where the water table is less than 15 cm (6 in) below the soil surface *(22).* Although capable of existing on soils with moisture regimes tending toward ustic or xeric, it grows poorly; frequently, tops die back in years of drought.

The soil organic horizon under mature stands ranges from less than 7 to more than 57 cm (2.8 to 22.5 in); the average depth increases from 11.4 cm (4.5 in) on soils with good drainage to 43.2 cm (17.0 in) on poorly drained soils *(15).* Commonly, the majority of roots, especially fine roots, are concentrated just below the organic horizon. The importance of the organic horizon as a continual supply of available nutrients for western hemlock cannot be overstated. In coastal British Columbia, earthworms are common in the organic horizons, even where the pH is less than 4; earthworms may play an important role in making nutrients available for root uptake. On many soils of Oregon and Washington, however, rooting depths exceed 1 m (3.3 ft).

Soil reaction (pH) under stands containing western hemlock ranges from less than 3.0 to nearly 6.0 in the organic horizons. The pH in the surface mineral horizons ranges from 4.0 to 6.3 and that of the C horizon from 4.8 to 6.2 *(21).* Optimum range of pH for seedlings is 4.5 to 5.0.

Western hemlock is highly productive on soils with a broad range of available nutrients. Evidence from various locations on the Pacific coast suggests that the productivity of western hemlock increases as soil nitrogen increases *(15,21).* There is no evidence that seedlings prefer ammonium over nitrate ions *(32).* Phosphorus may be limiting on some sites as suggested by data from Oregon showing a strong relation between site index and soil phosphorus *(21).* Although the requirement of western hemlock for cations is unclear, rooting habit and field data suggest that it requires or tolerates considerable amounts of calcium.

The range in elevation at which western hemlock grows is broad, from sea level to 2130 m (7,000 ft); its distribution varies by latitude and mountain range. On the coast, western hemlock develops best between sea level and 610 m (2,000 ft); in the Rocky Mountains, between 490 and 1280 m (1,600 and 4,200 ft) *(26).*

Associated Forest Cover

Western hemlock (fig. 2) is either a major or a minor component in at least 20 forest cover types of the Society of American Foresters *(6).*

	Pacific coast	Rocky Mountains
202 White Spruce–Paper Birch	X	
205 Mountain Hemlock	X	X
206 Engelmann Spruce–Subalpine Fir		X
210 Interior Douglas-Fir		X
212 Western Larch		X
213 Grand Fir		X
215 Western White Pine		X
218 Lodgepole Pine		X
221 Red Alder		

Figure 2-Open-grown western hemlock, Coeur d'Alene National Forest, ID.

		Pacific Coast	Rocky Mountains
222	Black Cottonwood-Willow	X	
223	Sitka Spruce	X	
224	Western Hemlock	X	X
225	Western Hemlock-Sitka Spruce	X	
226	Coastal True Fir-Hemlock	X	
227	Western Redcedar-Western Hemlock	X	X
228	Western Redcedar	X	
229	Pacific Douglas-Fir	X	
230	Douglas-Fir-Western Hemlock	X	X
231	Port Orford-Cedar	X	
232	Redwood	X	

The forest cover types may be either seral or climax.

Tree associates specific to the coast include Pacific silver fir (*Abies amabilis*), noble fir (*A procera*), bigleaf maple (*Acer mucrophyllum*), red alder (*Alnus rubra*), giant chinkapin (*Castanopsis chrysophylla*), Port-Orford-cedar (*Chamaecyparis lawsoniana*), Alaska-cedar (*C. nootkatensis*), incense-cedar (*Libocedrus decurrens*), tanoak (*Lithocarpus densiflorus*), Sitka spruce (*Picea sitchensis*), sugar pine (*Pinus lumbertiana*), redwood (*Sequoia sempervirens*), and California laurel (*Umbellularia californica*). Associates occurring in both the Pacific coast and Rocky Mountain portions of its range include grand fir (*Abies grandis*), subalpine fir (*A lasiocarpa*), paper birch (*Betula papyrifera*), western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmannii*), white spruce (*P. glauca*), lodgepole pine (*Pinus contorta*), western white pine (*P. monticola*), ponderosa pine (*P. ponderosa*), black cottonwood (*Populus trichocarpa*), Douglas-fir (*Pseudotsuga menziesii*), Pacific yew (*Taxus brevifolia*), western redcedar (*Thuja plicata*), and mountain hemlock (*Tsuga mertensiana*).

Western hemlock is a component of the redwood forests on the coasts of northern California and adjacent Oregon. In Oregon and western Washington, it is a major constituent of the *Picea sitchensis*, *Tsuga heterophylla*, and *Abies amabilis* Zones and is less important in the *Tsuga mertensiana* and Mixed-Conifer Zones (7). In British Columbia, it is a major element of the *Tsuga heterophylla-Picea sitchensis*, *Tsuga heterophylla-Abies amabilis*, *Tsuga heterophylla*, *Abies amabilis-Tsuga heterophylla*, and *Abies amabilis–Tsuga mertensiana* Vegetation Zones; it is confined to a distinct understory portion or to moist sites in the *Pseudotsuga menziesii-Tsuga heterophylla* and *Pseudotsuga menziesii* Zones (25). In the Rocky Mountains, it is present in the *Thuja plicata* and *Tsuga heterophylla* Vegetation Zones and the lower portion of the *Abies lasiocarpa* Zone (26).

Various persons have described the plant associations and biogeocoenoses in which western hemlock is found; more than 75 are listed for the west coast and more than 30 for the Rocky Mountains (25).

Little effort has been made to correlate the communities with one another.

Because of its broad range, western hemlock has a substantial number of understory associates. In its Pacific coast range, common shrub species include the following (starred species are also common associates in the Rocky Mountains): vine maple *(Acer circinatum)*, Sitka alder* *(Alnus sinuata)*, Oregongrape *(Berberis nervosa)*, snowbrush ceanothus* *(Ceanothus velutinus)*, salal *(Gaultheria shallon)*, oceanspray" *(Holodiscus discolor)*, rustyleaf menziesia* *(Menziesia ferruginea)*, devilsclub* *(Oplopanax horridus)*, Oregon boxwood" *(Pachistima myrsinites)*, Pacific ninebark* *(Physocarpus capitatus)*, Pacific rhododendron *(Rhododendron macrophyllum)*, stink currant *(Ribes bracteosum)*, prickly currant* *(R. lacustre)*, thimbleberry* *(Rubus parviflorus)*, salmonberry *(R. spectabilis)*, trailing blackberry *(R. ursinus)*, Pacific red elder *(Sambucus callicarpa)*, common snowberry* *(Symphoricarpos albus)*, Alaska blueberry *(Vaccinium alaskaense)*, big huckleberry *(V. membranaceum)*, ovalleaf huckleberry *(V. ovalifolium)*, evergreen huckleberry *(V. ovatum)*, and red huckleberry *(V. parvifolium)*. The following are other common associates in the Rocky Mountains: creeping western barberry *(Berberis repens)*, russet buffaloberry *(Shepherdia canadensis)*, birchleaf spirea *(Spiraea betulifolicz)*, dwarf blueberry *(Vaccinium caespitosum)*, globe huckleberry *(V. globulare)*, and grouse whortleberry *(V. scoparium)*.

Common herbaceous species include the ferns: maidenhair fern *(Adiantum pedatum)*, ladyfern *(Athyrium filix-femina)*, deerfern *(Blechnum spicant)*, mountain woodfern *(Dryopteris austriaca)*, oakfern *(G-ymnocarpium dryopteris)*, swordfern *(Polystichum munitum)*, and bracken *(Pteridium aquilinum)*. Herb associates include vanillaleaf *(Achlys triphylla)*, wild ginger *(Asarum caudatum)*, princes-pine *(Chimaphila umbellata)*, little princes-pine *(C. menziesii)*, queenscup *(Clintonia uniflora)*, cleavers bedstraw *(Galium aparine)*, sweetscented bedstraw *(G. triflorum)*, twinflower *(Linnaea borealis)*, Oregon oxalis *(Oxalis oregana)*, one-sided pyrola *(Pyrola secunda)*, feather solomonplume *(Smilacina racemosa)*, starry solomonplume *(S. stellata)*, trefoil foamflower *(Tiarella trifoliata)*, coolwort foamflower *(T. unifoliata)*, white trillium *(Trillium ovatum)*, roundleaf violet *(Viola orbiculata)*, evergreen violet *(V. sempervirens)*, and common beargrass *(Xerophyllum tenax)*.

Life History

Reproduction and Early Growth

Flowering and Fruiting-Western hemlock is monoecious; male and female strobili develop from separate buds of the previous year. Female strobili occupy terminal positions on lateral shoots, whereas the male strobili cluster around the base of the needles (4). Flowering and pollination begin from mid-April to late April in western Oregon and continue into late May and June in coastal Alaska. The solitary, long (19 to 32 mm; 0.75 to 1.25 in), pendent cones mature 120 to 160 days after pollination. Time of maturity of cones on the same branch is variable; ripe cones change from green to golden brown. The cone-scale opening mechanism does not appear to develop fully until late in the ripening period. Seeds are usually fully ripe by mid-September to late September, but cone scales do not open until late October. Empty cones often persist on the tree for 2 or more years.

Although flowering may begin on lo-year-old trees, regular cone production usually begins when trees reach 25 to 30 years of age. Mature trees are prolific producers of cones. Some cones are produced every year, and heavy crops occur at average intervals of 3 to 4 years; however, for a given location, the period between good crops may vary from 2 to 8 years or more. For example, in Alaska, good seed crops occur on an average of 5 to 8 years.

Seed Production and Dissemination-There are 56,760 to 83,715 cones per hectoliter (20,000 to 29,500/bu). Each cone contains 30 to 40 small seeds. Extraction and cleaning yields an average of 0.79 kg of seed per hectoliter (0.61 lb/bu) of cones. There are 417,000 to over 1,120,000 with an average 573,000 seeds per kilogram (189,000 to 508,000/lb; average 260,000). Slightly less than one-half of the seeds extracted from the cones are viable.

In coastal Oregon, more than 19.8 million seeds per hectare (8 million/acre) were released during each of two good seed years from loo-year-old stands, or about 30.3 kg/ha (27 lb/acre). In 1951, a hemlock-spruce stand in Alaska produced 96.4 kg/ha (86 lb/acre) of western hemlock seed. In the Rocky Mountains, western hemlock consistently produces more seed than its associates in the *Tsuga heterophylla Zone.*

Cone scales of western hemlock open and close in response to dry and wet atmospheric conditions. Under wet conditions, seed may be retained in the cones until spring. Western hemlock seed falls at a rate of 80 cm (31 in) per second *(27)*. Released in a strong wind, it can be blown more than 1.6 km (1 mi). In a wind of 20 km (12.5 mi) per hour, seed released at a height of 61 m (200 ft) traveled up to 1160 m (3,800 ft); most fell within 610 m (2,000 ft) of the point of release *(19)*. Seedfall under a dense canopy is 10 to 15 times greater than that within 122 m (400 ft) of the edge of timber in an adjacent clearcut.

Seedling Development-Western hemlock seeds are not deeply dormant; stratification for 3 to 4 weeks at 1" to 4" C (33" to 39" F) improves germination and germination rate. The germination rate is sensitive to temperature; optimum temperature appears to be 20" C (68" F). For each 5" C (9" F) drop below the optimum, the number of days required for germination is nearly doubled. Given sufficient time (6 to 9 months) and an absence of pathogens, western hemlock will germinate at temperatures just above freezing (4). Germination is epigeal. Western hemlock seeds remain viable only into the first growing season after seedfall.

Provided adequate moisture is available, seed germination and germinant survival are excellent on a wide range of materials. Seeds even germinate within cones still attached to a tree. Western hemlock germinates on both organic and mineral seedbeds; in Alaska, establishment and initial growth are better on soils with a high amount of organic matter. Mineral soils stripped of surface organic material commonly are poor seedbeds because available nitrogen and mineral content is low.

In Oregon and Washington, exposed organic materials commonly dry out in the sun, resulting in the death of the seedling before its radicle can penetrate to mineral soil and available moisture. In addition, high temperatures, which may exceed 66" C (150" F) at the surface of exposed organic matter, are lethal. Under such moisture and temperature conditions, organic seedbeds are less hospitable for establishment of seedlings than mineral seedbeds *(27)*. Burning appears to encourage natural regeneration on Vancouver Island; after the third growing season, burned seedbeds had 58 percent more seedlings with better distribution than unburned seedbeds *(17)*.

Decaying logs and rotten wood are often favorable seedbeds for western hemlock. Decayed wood provides adequate nutrition for survival and growth of seedlings *(23)*. In brushy areas, seedlings commonly grow on rotten wood where there is minimum competition for moisture and nutrients. Seedlings established on such materials frequently survive in sufficient numbers to form a fully stocked stand by sending roots into the soil around or through a stump or log.

Because western hemlock can thrive and regenerate on a diversity of seedbeds, natural regeneration can be obtained through various reproduction methods, ranging from single-tree selection to clearcutting. Through careful harvesting of old-growth stands, advance regeneration often results in adequately stocked to overstocked stands.

Western hemlock is difficult to grow in outdoor nurseries. Container-grown stock appears to result in higher quality seedlings, less damage to roots, and better survival than does bare root stock.

Initial growth is slow; 2-year-old seedlings are commonly less than 20 cm (8 in) tall. Once established, seedlings in full light may have an average growth rate of 60 cm (24 in) or more annually.

Vegetative Reproduction-Western hemlock can be propagated by layering and from cuttings. Seedlings that die back to the soil surface commonly sprout from buds near the root collar. Sprouting does not occur from the roots or the base of larger saplings.

Western hemlock grafts readily. Incompatibility between the scion and rootstock does not appear to be a problem. Growth of grafted material is better than that of rooted material.

Sapling and Pole Stages to Maturity

Growth and Yield-Western hemlock (fig. 3) may form pure stands or be a component of mixed stands. Young stands vary in stocking, but understocking is infrequent. Natural 20-year-old stands can have 14,800 to 24,700 or more stems per hectare (6,000 to 10,000/acre). Stocking levels of 1,480 to 1,790 stems per hectare (600 to 725/acre) at crown closure are believed to provide the best yields if commercial thinnings are part of the management regime *(12)*. If thinnings are not planned, stocking levels as low as 740 well-distributed trees per hectare (300/acre) can provide maximum yields at rotation age (27).

The response of western hemlock to nitrogen fertilizer is extremely variable. It appears to vary by geographic location and stocking level. For overstocked stands, a combination of precommercial thinning and fertilizer often gives the best response.

Comparative yield data from paired British plantations strongly suggest that western hemlock commonly outproduces two of its most important associates, Douglas-fir and Sitka spruce *(1)*. Natural stands of western hemlock along the Pacific coast attain appreciably higher yields than Douglas-fir stands having the same site index (34); the weighted mean annual increment of western hemlock for some common forest soils in Washington is 33 to 101 percent more than the mean annual increment for Douglas-fir *(30)*. On the Olympic Peninsula, western hemlock out-produces Douglas-fir by 25 to 40 percent. Similar relationships occur in south coastal British Columbia *(12). The* higher mean annual in-

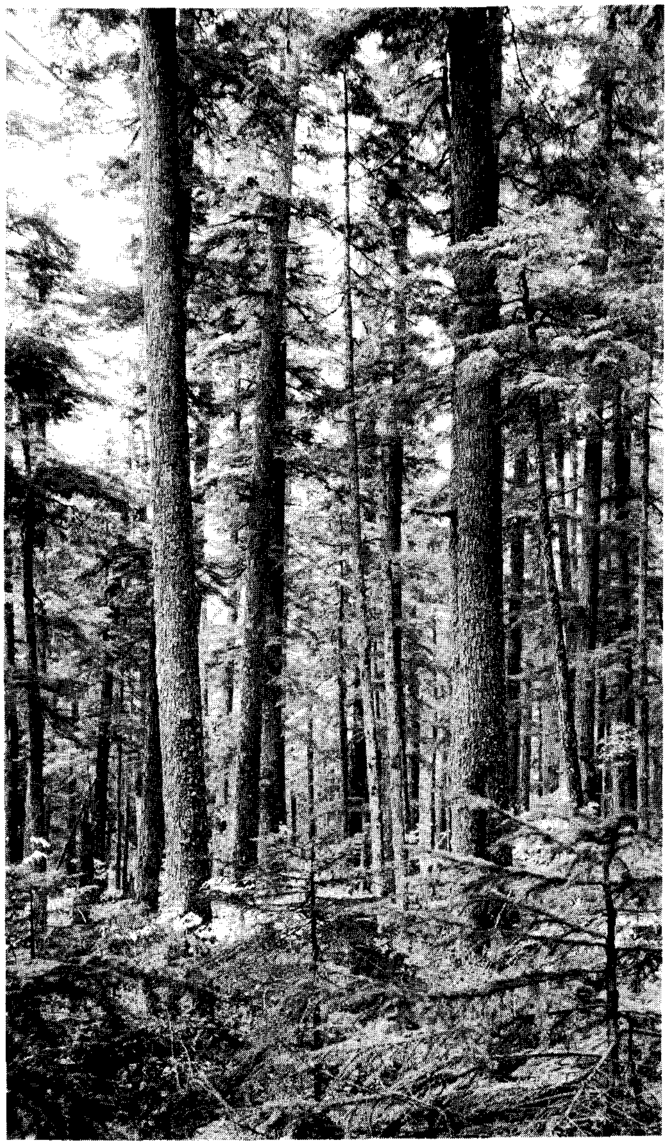

Figure 3-A *mature stand of western hemlock in Washington Trees average about 76 cm (30 in) in d. b.h.*

crement of western hemlock apparently is due to the ability of western hemlock stands to support more trees per hectare; individual trees also have better form than other species and hence better volume (at least 4 to 14 percent) *(34).*

Mixed stands of western hemlock and Sitka spruce are especially productive. In the *Picea sitchensis* Zone of Oregon and Washington, the mean annual increment of such stands frequently exceeds 42 m^3/ha (600 $ft^3/acre$). At higher elevations and farther north, mixed stands of western hemlock and Pacific silver fir are also highly productive.

Yield data for natural stands are given in table 1. Volumes predicted for normally stocked stands may actually underestimate potential yields by 20 to 50 percent. Data from British Columbia suggest greater yields can be had if a high number of stems per hectare are maintained *(12).* Yields of western hemlock on the best sites can exceed 1848 m^3/ha (26,400 $ft^3/acre$) at 100 years of age.

Western hemlock forests are among the most productive forests in the world. The biomass production of several western hemlock stands with a site index (base 100 years) of 43 m (140 ft) was investigated at the Cascade Head Experimental Forest near Lincoln City, OR. The biomass of standing trees of a 26-year-old, nearly pure western hemlock stand was 229 331 kg/ha (204,614 lb/acre) and that of a 121-year-old stand with a spruce component of 14 percent was 1 093 863 kg/ha (975,966 lb/acre). Net primary productivity per year for these two stands was estimated to be 37 460 and 22 437 kg/ha (33,423 and 20,019 lb/acre). Net primary productivity appears to peak at about 30 years, then declines rapidly for about 50 years. Foliar biomass in the stands at Cascade Head averages 22 724 kg/ha (20,275 lb/acre) with a leaf area of 46.5 m^2/m^2 (46.5 ft^2/ft^2) *(8,10).* By comparison, available data indicate much lower values for highly productive Douglas-fir stands—12 107 kg/ha and 21.4 m^2/m^2 (10,802 lb/acre and 21.4 ft^2/ft^2), respectively.

On the best sites, old-growth trees commonly reach diameters greater than 100 cm (39.6 in); maximum diameter is about 275 cm (108 in). Heights of 50 to 61 m (165 to 200 ft) are not uncommon; maximum height is reported as 79 m (259 ft). Trees over 300 years old virtually cease height growth (27). Maximum ages are typically over 400 but less than 500 years. The maximum age recorded, in excess of 700 years, is from the Queen Charlotte Islands *(16).* Several major associates (Douglas-fir, western redcedar, Alaska-cedar) typically reach much greater ages.

Rooting Habit-Western hemlock is a shallow-rooted species; it does not develop a taproot. The roots, especially the fine roots, are commonly most abundant near the surface and are easily damaged by harvesting equipment and fire.

Reaction to Competition-Western hemlock is rated to be very tolerant of shade. Only Pacific yew and Pacific silver fir are considered to have equal or greater tolerance of shade than western hemlock.

Western hemlock responds well to release after a long period of suppression. Advance regeneration 50 to 60 years old commonly develops into a vigorous, physiologically young-growth stand after complete removal of the overstory; however, poor response to release has been noted for suppressed trees over 100 years old. Advance regeneration up to 1.4 m (4.5 ft) tall appears to respond better to release than taller individuals. Because of its shade tolerance, it is an ideal species for management that includes partial cutting; however, if it is present and the management goal is for a less tolerant species, normal partial cutting practices are not recommended.

Under conditions of dense, even-aged stocking, early natural pruning occurs, tree crowns are usually narrow, and stem development is good. Given unrestricted growing space, the quality of western hemlock logs is reduced because of poorly formed stems and persistent branches. Trees that develop in an understory vary greatly in form and quality.

The successional role of western hemlock is clear; it is a climax species either alone or in combination with its shade-tolerant associates. Climax or near-climax forest communities along the Pacific coast include western hemlock, western hemlock-Pacific silver fir, western hemlock-western redcedar, Pacific silver fir-western hemlock-Alaska-cedar, and western hemlock-mountain hemlock. The longevity of some associates of western hemlock makes it difficult to determine if some of these near-climax communities will develop into pure western hemlock stands or if western hemlock will ultimately be excluded.

Climax or near-climax communities in the Rocky Mountains include western hemlock, western hemlock-western redcedar, and occasionally subalpine fir-western hemlock. In the last community, western hemlock plays a distinctly minor role (26).

Table 1-Characteristics of fully stocked, 100-year-old western hemlock stands in Oregon (OR), Washington (WA), British Columbia (BC), and Alaska (AK) (adapted from *2*)

Item	Average site index at base age 100 years[1]				
	61 m or 200 ft	52 m or 170 ft	43 m or 140 ft	34 m or 110 ft	26 m or 85 ft
Avg. height, m					
OR/WA	58.8	49.7	40.8	31.7	—
BC	—	50.0	40.8	31.7	22.3
AK	—	—	38.4	29.3	20.7
Avg. d.b.h., cm					
OR/WA	58	54	49	42	—
BC/AK	—	44	40	31	22
Stocking[2], trees/ha					
OR/WA	299	339	400	526	—
BC/AK	—	482	573	865	1,384
Basal area*, m^2/ha					
OR/WA	83.3	81.7	79.0	75.3	—
BC/AK	—	75.5	73.0	67.5	59.9
Whole tree volume*, m^3/ha					
OR/WA	1771	1498	1218	938	—
BC	—	1449	1228	938	612
AK	—	—	1158	868	560
Avg. height, ft					
OR/WA	192.9	163.1	133.9	104.0	—
BC	—	184.0	133.9	104.0	73.2
AK	—		126.0	96.1	67.9
Avg. d.b.h., in					
OR/WA	23.0	21.4	19.2	16.5	—
BC/AK	—	17.5	15.6	12.4	8.8
Stocking*, trees/acre					
OR/WA	121	137	162	213	—
BC/AK	—	195	232	350	560
Basal area*, $ft^2/acre$					
OR/WA	362.9	355.9	344.1	328.0	—
BC/AK	—	328.9	318.0	294.0	261.0
Whole tree volume[2], $ft^3/acre$					
OR/WA	25,295	21,394	17,406	13,405	—
BC	—	20,693	17,549	13,405	8,746
AK	—	—	16,549	12,405	8,003

[1]Site indexes range within 4.6 m (15 ft) of the averages
[2]Trees larger than 3.6 cm (1.5 in) in d.b.h.

Damaging Agents-Many agents adversely affect the growth, health, and quality of western hemlock trees and stands.

Because of its thin bark and shallow roots, western hemlock is highly susceptible to fire. Even light ground fires are damaging. Prescribed burning is an effective means of eliminating western hemlock advance regeneration from a site.

Because of its shallow roots, pole-size and larger stands of western hemlock are subject to severe windthrow. Thousands of hectares of young stands dominated by coastal western hemlock have originated after such blowdown.

Western hemlock suffers frost damage in the Rocky Mountains, especially along the eastern edge of its range where frost-killed tops are reported *(20,26)*. Snowbreak occurs locally; it appears to be most common east of the Cascade and Coast Mountains, and especially in the Rocky Mountains. On droughty sites, top dieback is common; in some exceptionally dry years, entire stands of hemlock saplings die. Suddenly exposed saplings may suffer sunscald. Excessive amounts of soil moisture drastically reduce growth.

Western hemlock is one of the species most sensitive to damage by sulfur dioxide *(16).* Spring applications of the iso-octyl esters of 2,4-D and 2,4,5-T in diesel oil can kill leader growth of the last 3 years.

Severe fluting of western hemlock boles is common in southeast Alaska, much less common on Vancouver Island, and relatively uncommon in Washington and Oregon. There appears to be a clinal gradient from north to south; the causal factor is not known.

No foliage diseases are known to cause serious problems for western hemlock.

Dwarf mistletoe ***(Arceuthobium tsugense)*** is a serious parasite along the Pacific coast from California nearly to Glacier Bay, AK; its presence on western hemlock in the Rocky Mountain States is unconfirmed. It increases mortality, reduces growth, lowers fiber quality, and provides an entryway for decay fungi. Uninfected to lightly infected trees may have a greater growth in volume (40 percent) and height (84 percent) than severely infected trees; in mature stands, volume losses as high as 4.2 m^3/ha (60 ft^3/acre) per year have been reported (29). Dwarf mistletoe in western hemlock is easy to control; success is nearly 100 percent if methods of sanitation are good.

Armillaria mellea, Heterobasidion annosum, Phaeolus schweinitzii, Laetiporus sulphureus, Inonotus tomentosus, Poria subacida, and ***Phellinus weiri*** are the major root and butt pathogens of western hemlock. ***Armillaria mellea*** occurs widely, seldom kills trees directly, and is not a major source of cull.

Heterobasidion annosum, the most serious root pathogen of western hemlock, can limit the alternatives available for intensive management (3). The incidence of infected trees in unthinned western hemlock stands ranges from 0 to more than 50 percent. In some thinned stands, every tree is infected. ***Heterobasidion annosum*** spores colonize freshly cut stumps and wounds; the spreading mycelium infects roots and spreads to adjacent trees through root grafts. Treating stumps and wounds with chemicals can reduce the rate of infection.

Phellinus weiri is a common root pathogen where Douglas-fir is or was a major component of the stand. In the Rocky Mountains, a similar relationship may exist with western redcedar. ***Phellinus weiri*** rapidly extends up into the bole of western hemlock. The first log is frequently hollow; only the sapwood remains. The only practical controls for *P. weiri* are pulling out the stumps and roots or growing resistant species.

High risk bole pathogens include ***Echinodontium tinctorium, Heterobasidion annosum,*** and ***Phellinus weiri. Echinodontium tinctorium*** causes extensive decay in overmature stands in the Rocky Mountains. It is less destructive in immature stands, although it is found in trees 41 to 80 years old; 46 percent of the trees in this age group in stands studied were infected. ***Echinodontium tinctorium*** is of little consequence on the coast. ***Heterobasidion annosum*** spreads from the roots into the bole of otherwise vigorous trees. On Vancouver Island, an average of 24 percent (range 0.1 to 70 percent) of the volume of the first 5-m (16-ft) log can be lost to ***H. annosum*** *(24).*

Rhizina undulata, a root rot, is a serious pathogen on both natural and planted seedlings on sites that have been burned. It can kill mature trees that are within 8 m (25 ft) of the perimeter of a slash burn *(3).*

Sirococcus strobilinus, the sirococcus shoot blight, causes dieback of the tip and lateral branches and kills some trees in Alaska; the potential for damage is not known (27).

Of the important insects attacking western hemlock, only three do not attack the foliage. A seed chalcid ***(Megastigmus tsugae)*** attacks cones and seeds; the larva feeds inside the seed. This insect normally is not plentiful and is of little consequence to seed production *(14).* A weevil ***(Steremnius carinatus)*** causes severe damage in coastal British Columbia by girdling seedlings at the ground line. In the Rocky Mountains, the western larch borer *(Tetropium velutinum)* attacks trees that are weakened by drought, defoliated by insects, or scorched by fire; occasionally it kills trees (9).

Since 1917, there have been only 10 years in which an outbreak of the western blackheaded budworm *(Acleris gloverana)* did not cause visible defoliation somewhere in western hemlock forests (28). Extensive outbreaks occur regularly in southeast Alaska, on the coast of British Columbia, in Washington on the south coast of the Olympic Peninsula and in the Cascade Range, and in the Rocky Mountains. In 1972, nearly 166 000 ha (410,000 acres) were defoliated on Vancouver Island alone. Damage by the larvae is usually limited to loss of foliage and related growth reduction and top kill. Mortality is normally restricted to small stands with extremely high populations of budworms.

The western hemlock looper ***(Lambdina fiscellaria lugubrosa)*** has caused more mortality of western hemlock than have other insect pests. Outbreaks last 2 to 3 years on any one site and are less frequent than those of the budworm. The greatest number of outbreaks occurs on the south coast of British Columbia; the western hemlock looper is less prevalent farther north. Heavy attacks have been recorded for Washington and Oregon since 1889. The insect is less destructive in the interior forests. Although mortality is greatest in old growth, vigorous 80- to loo-year-old stands are severely damaged.

Two other loopers, the greenstriped forest looper *(Melanolophia imitata)* and the saddleback looper *(Ectropis crepuscularia),* cause top kill and some mortality. The phantom hemlock looper *(Nepytia phantasmaria)* in the coastal forest and the filament bearer *(Nematocampa filamentaria)* play minor roles, usually in association with the western hemlock looper (28).

The hemlock sawfly *(Neodiprion tsugae)* occurs over most of the range of western hemlock. Its outbreaks often occur in conjunction with outbreaks of the western blackheaded budworm. The larvae primarily feed on old needles; hence, they tend to reduce growth rather than cause mortality *(9).* The hemlock sawfly is considered the second most destructive insect in Alaska *(13).*

Black bear girdle pole-size trees and larger saplings or damage the bark at the base of the trees, especially on the Olympic Peninsula of Washington. Roosevelt elk and black-tailed deer browse western hemlock in coastal Oregon, Washington, and British Columbia. The snowshoe hare and the brush rabbit damage hemlock seedlings, principally by clipping off the main stem; clipping of laterals rarely affects survival of seedlings *(5).* Mountain beaver clip the stems and lateral branches of seedlings and girdle the base of saplings along the coast south of the Fraser River in British Columbia to northern California. Four years after thinning, evidence of girdling and removal of bark was present on 40 percent of the trees (5). Mortality results from both kinds of damage.

Special Uses

The forest industry recognizes western hemlock as an all-purpose raw material. It treats well and is used for pilings, poles, and railway ties. Strength and nailing characteristics make it a preferred species for construction lumber in North America and overseas. Better lumber grades are used for appearance and remanufacture products. Western hemlock has good-to-excellent pulping characteristics and is an important fiber source for groundwood, thermomechanical, kraft, and sulfite pulps.

Genetics

A natural cross between western hemlock and mountain hemlock, *Tsuga* x *jeffreyi* (Henry) Henry, has been reported from the Mount Baker area in Washington. Analysis of polyphenolic pigment suggests that chemical hybrids between western hemlock and mountain hemlock occur but are rare. Intergeneric hybridization between western hemlock and spruce has been discussed in the literature; although similarities exist between the two genera, they do not suggest hybridization *(31).*

Albino individuals or those similarly deficient in chlorophyll have been observed in the wild.

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