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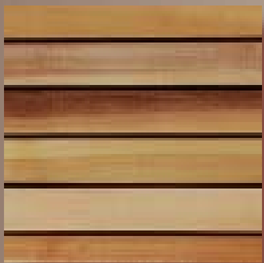

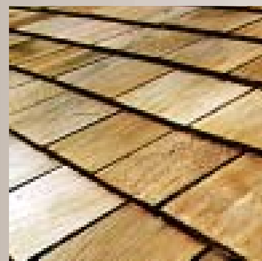

GROWTH, PROPERTIES AND USES OF WESTERN RED CEDAR

Josefina S. Gonzalez

This is a joint publication of Forintek Canada Corp., Western Red Cedar Lumber Association, and Western Red Cedar Export Association.

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GROWTH, PROPERTIES AND USES OF WESTERN RED CEDAR

(*Thuja plicata* **Donn ex D. Don.**)

by

Josefina S. Gonzalez
(Second Edition)

March 2004

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This is a revision and an update of the first edition published in August 1997. More recently acquired data have been incorporated but much of the original information remains the same. Tony Byrne (Forintek Canada Corp.) and Cees deJager (Western Red Cedar Lumber Association) co-ordinated and rewrote this edition. Josefina Gonzalez remains the author and, despite her retirement, kept a keen eye on the changes made. The following are particularly acknowledged for their contributions and comments: Bob Daniels, Les Jozsa, Gerry Middleton, Paul Morris, of Forintek Canada Corp., Karen Bartlett of the School of Occupational and Environmental Hygiene, UBC, and John Russell and Jacques Bousquet of the BC Ministry of Forests. Forestry Innovation Investment provided generous funding for this publication.

Credits:

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Figures by Susan Rollinson
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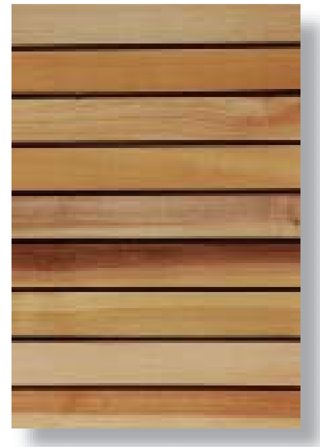
SUMMARY

Western red cedar is a common tree in Pacific Northwest Coastal and Interior rainforests of British Columbia. The tree is one of the longest lived and most decay- and insect-resistant softwood species in North America. As a result it can grow to a great size. The Pacific Northwest First Nations have a long history of using western red cedar wood, branches, bark and roots for their houses, their transportation, their clothes, their household, fishing and hunting items, and for ceremonial and religious purposes.

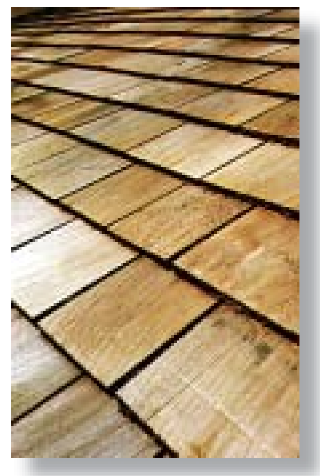
Measured on a standing wood volume basis BC has about 750 million cubic metres of western red cedar. More than half of that is found in the coastal region where it is the second most common conifer. Most of this is old-growth forest i.e., more than 250 years old. Close to 50 million cubic metres of the cedar growing in the coastal region is in parks and other protected areas. A significant amount is also included in the coastal "working" forest much of which has received, or is in the process of receiving, certification. "Second-growth" western red cedar is gradually coming on stream and, along with old-growth, is harvested for the high value wood it produces. The amount of western red cedar harvested fluctuates around 6 million cubic metres per year, an amount determined to be sustainable within the Annual Allowable Cut for the province.

Western red cedar wood is light in weight, uniformly textured, straight-grained and contains no resin. All these make the wood easy to work with. It is a preferred species in applications where decay-resistance, dimensional stability and good insulation value are important. The wood is used in many ways such as siding, decking, fencing, garden accessories, conventional and laminated house logs, utility poles, and specialty products such as interior paneling, musical instruments, and roofing shakes and shingles (often made from dead logs lying in forests). Although only sawmill residues are used in

pulping, its excellent fiber morphology is sought after in the production of pure or mixed kraft pulps for the manufacture of specialty paper products.



Western red cedar has been the subject of much scientific study, especially with regard to its unique chemical properties. The extractives in the heartwood affect its properties far out of proportion to the amounts present. These extractives give the wood its distinct character and significant new findings are being made on the extractives responsible for the high durability of red cedar. Uses for the wood oil and for the purified wood extractives are being developed. Oil extract from the leaves has been produced and sold in British Columbia since 1987. Research is ongoing to investigate the interrelationships between growth rate, wood density and wood durability under different silvicultural regimes. The data show that faster grown cedar is of lower wood density than old-growth but this will not affect its utility given that the major uses of western red cedar are for appearance or non-structural products. Work on the durability of second-growth cedar is in progress. There are strong indications that the extractive content is much higher in vigorous young trees than in inner heartwood portions of old-growth trees of similar age since seed germination. This may be largely because extractives are slowly degraded by microorganisms in standing old trees.



Western red cedar is one of the world's most thoroughly researched woods. This publication summarises much of what is known about the species to date and covers the growth, properties and uses of western red cedar.

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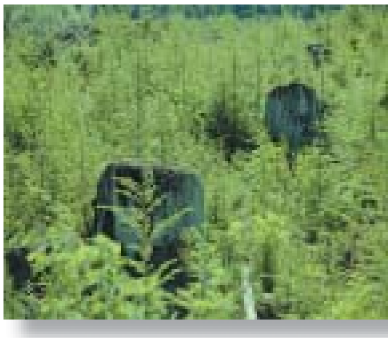

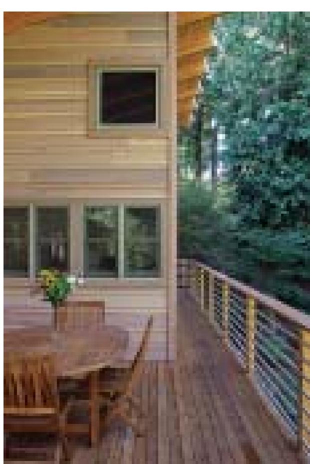

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INTRODUCTION

Western red cedar[1] (*Thuja plicata* Donn ex D. Don) is one of the two arborvitae species native to North America; the other is eastern white cedar, also known as eastern arborvitae (*Thuja occidentalis L.*) (Hosie 1969). They are commonly called "cedar" but they are not true cedars; the true cedars belong to the genus *Cedrus* and are not native to North America. To add to the confusion, the name "cedar" is also given to other species of different genera (e.g., Alaska-cedar (*Chamaecyparis nootkatensis* (D.Don) Spach), eastern red cedar (*Juniperus virginiana* L.) and incense-cedar (*Calocedrus decurrens* (Torr.) Florin).

Arborvitae is latin for *l'arbre de vie* ("tree of life"), the name given by the king of France to eastern white cedar. In the 16th Century, extracts of this plant were given by the North American First Nations to members of the Jacques Cartier expedition as a cure for scurvy (Harlow *et al.* 1979). Giant arborvitae might therefore be a more logical name for *Thuja plicata* than the more commonly used western red cedar. Not only is the tree massive, it is held in high esteem by the Pacific Northwest Coast First Nations for its healing and spiritual powers, and for the important role it plays in their art and culture (Stewart 1984). The wood of western red cedar has been used for making canoes, building lodges, and carving totem poles; the bark, for weaving into mats and baskets, rope and clothing; and the roots, for making watertight baskets. Some of the plethora of items made from western red cedar by the First Nations from the roots, trunk, bark and branches of the tree are listed in Table 1. Trees, from which planks or the bark have been harvested historically, show scarring and are known today as culturally modified trees. Trees that were culturally modified before 1846 are considered archeological sites and are protected under the BC Heritage Conservation Act (BC Market Outreach Network 2003a). The coastal First Nations people still use cedar logs for traditional or cultural purposes such as canoes, carved poles, masks and long houses.

Western red cedar is abundant in the province of British Columbia and grows nowhere else in Canada. In 1988, western red cedar was declared British Columbia's official tree. It is a particularly common species in the coastal

[1] *The first edition of this publication used the word redcedar, a technically more correct name. For this edition the name most commonly used in the market has been used.*

> *"Like the bountiful salmon of the sea, the ubiquitous tree gave of itself to sustain and enrich their lives."*
>
> (Stewart 1984)

region. Cedar was first harvested by the early European settlers in the mid-1800s and was first used mainly for roofing shakes and shingles. Since that time the tree has formed the basis for a large and unique forest products industry. Although cedar products are also manufactured in the Pacific Northwest region of the USA, Canada is by far the larger producer, supplying demand for cedar products both in North America and overseas. The most significant offshore importers of western red cedar are Europe, Australia, New Zealand and Japan.

In 2002 western red cedar lumber production was reported to be 903 million board feet or 2.1 million cubic metres (COFI 2003). This represents 6.4% of the total BC lumber production. The volume of western red cedar lumber exported was about 1.7 million cubic metres (m^3) worth approximately $1 billion. About 85% of this was exported to the United States. In addition, approximately 10 million square metres (m^2) of siding and over 20 million m^2 of shingles and shakes were exported, with the USA again as the largest importer.

Western red cedar is one of the world's most thoroughly researched woods. This publication summarises much of what has been learned about the species to date and covers the growth, properties and uses of western red cedar.

TABLE 1.

Some of the known uses of western red cedar by the Pacific Northwest Coast First Nations (after Stewart 1984)

Wood	Bark, branches and roots
Planks and boards for walls, roofs and screens	Baskets, bags and other weaving
Building posts and beams	Ropes, string, bindings and fine twine
Carved poles, posts and figures	Blankets
Steambent wood boxes, chests and bowls	Bedding
Canoes	Towels
Canoe bailing scoops and shaped storage boxes	Skirts
Fishing floats and fishing spears	Mats and ponchos
Salmon traps	Hats
Fire drills	Childrens' balls
Arrows and quivers	Belts, necklaces and neck rings
Childrens' cradles	Decorations
Cooking tongs	Headdresses
Looms	Emergency canoes
Drying racks	Canoe bailers
Tally sticks	Canoe sails
Toys	Nets
Paint brushes	Berry holders
Ceremonial masks and shamanic objects	Tree climbing equipment
Rattles and whistles	Hunting equipment
Speakers' staffs	
Feast dishes	
Grave monuments	
Tombs	
Basket frames	
Weaving frames	

THE FOREST RESOURCE

The Tree

Western red cedar normally grows to heights of 45 to 60 m and diameters of 2.4 m, but more massive individuals are also common. The largest western red cedar in the world is located at Quinault Lake, Olympic National Park, Washington, USA. The tree is 22 m in circumference and 55 m tall and estimated to be over 2000 years old (University of Bonn 2003). Though it is now hollow, the Quinault Lake Cedar once had an estimated wood volume of 500 m³. The largest tree in Canada is a western red cedar growing at Cheewhat Lake in the Pacific Rim National Park. It is 55.5 m tall, 18.3 m in circumference and contains 449 m³ of wood (Government of BC 2003 Conservation Centre Database).

The cones are densely clustered, turning woody and brown as they mature.

The tree has a long and narrow conical crown, with drooping and spreading branches that turn upwards at the ends. The scale-like leaves are small, 3 to 6 mm long, yellow-green, shiny, and arranged in sprays. The leaves lie in pairs, the side pair always folded to the alternate flat pair, creating a pressed appearance in the branches. The cones are 1 to 2 cm long, with a small number of weakly spine-tipped scales. The densely clustered, green cones turn woody and brown as they mature. The base of the trunk is often fluted, flared and broadly buttressed, especially in open-grown trees (Farrar 1995). The root system is shallow and wide-spreading, but strong. The bark is thin, seldom over 2.5 cm thick, stringy and fibrous. It is cinnamon-red, smooth and shiny on young stems; it is greyish brown and shredded, forming flat narrow ridges on old trunks.

Distribution

Western red cedar grows along the Pacific coast from northern California to southeastern Alaska (Figure 1). In Canada, western red cedar's growth is limited to British Columbia. It is a major species in the Coastal Western Hemlock biogeoclimatic zone and most of the standing volume is found in this zone. It is also found in the Interior Cedar-Hemlock (ICH) biogeoclimatic zone (Meidinger and

FIGURE 1.
Natural range of western red cedar (after Minore 1990)

Pojar 1991), the Coastal Douglas-fir zone, lower elevations in the Mountain Hemlock zone and the wetter parts of the Montane Spruce zone (transitional to the ICH zone). It grows occasionally in the Subalpine Fir zone.

The elevation limits of western red cedar vary with latitude. It grows from sea level to 915 m in southeastern Alaska; up to 1200 m on the BC coast and from 320 to 2130 m in the interior of British Columbia; and up to 2300 m in Oregon (Burns and Honkala 1990; Minore 1983). Pojar and Mackinnon (1994) noted that western red cedar "abruptly stops at Pt. Frederick Sound just as it abruptly stops at about 300 m elevation in southern southeast Alaska."

The important associates of western red cedar along the Pacific slope are Sitka spruce, western hemlock, Douglas-fir, grand and amabilis firs, Pacific yew, red alder, black cottonwood and bigleaf maple. In the mountain forests, its principal associates are western larch, western white pine, western hemlock, grand fir, Douglas-fir, and Engelmann spruce.

"Second-growth" western red cedar is gradually coming on stream and, along with old-growth, is harvested for the high value wood it produces.

Western red cedar is also grown outside its natural range (Minore 1983). It has been planted occasionally as an ornamental tree in Mid and North Atlantic United States, in the Ukraine, in southern Australia, Britain, and Switzerland. It is used in forest plantations in England, Ireland, Scotland and Wales, and is almost a naturalized species in West Germany. Experimental stands have been established in Poland. It has been grown in Italy and France, and in the Nordic countries of Denmark, Norway, and Finland. Western red cedar has been planted extensively in New Zealand, but has shown little promise in the Union of South Africa or Honshu, Japan (Minore 1983).

Standing Volume

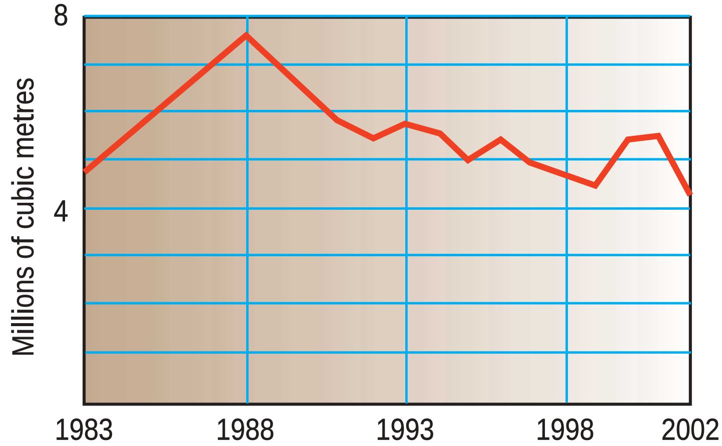
On a standing volume basis BC has been reported to have about 750 million m^3 of western red cedar (BC Market Outreach Net 2003a) with about 80% of that found in the coastal region. Western red cedar represents 20% of the total standing volume of mature softwoods on the coast, and 2% of the total BC mature softwood inventory combined (Council of Forest Industries 2001). Western red cedar accounts for the second largest mature timber volume on the coast, second to western hemlock.

BC Ministry of Forests inventories western red cedar and yellow cypress together and the figures quoted here are based on the assumption that 70% of the total cedars inventory is western red cedar (J. Bousquet Personal Communication). The most recent inventory information available (Seamless Forest Cover Inventory database) estimates the total standing volume of cedar in the coastal region, at about 440 million m^3. Nearly three-quarters of this is old-growth forest i.e., more than 250 years old. A significant amount of cedar is included in the "working" forest, much of which has received certification, or is in the process of receiving certification (BC Market Outreach Network 2003b).

Some 35% or about 145 million m^3 of the coastal volume of cedar is within the Timber Harvesting Landbase (THLB). About 285 million m^3 or 65% is within the Non-Timber Harvesting Landbase area.

Close to 50 million m^3 of the cedar growing in the coast region is reported to be in parks and other protected areas (BC Market Outreach Network 2003a). However, this figure is an underestimate because it does not reflect the creation of parks in the late 1990's.

FIGURE 2.
Volume of cedar harvested along BC's coast 1983-2002 (after Ministry of Forests' Annual Reports)



Harvests

Less than 1% of BC's cedar growing stock volume is harvested each year, with three-quarters of the harvest originating from the coastal forest areas.

Clearcut harvesting is now being phased out on the BC coast. A system called variable retention to keep the forest structure intact is now widely practised.

The volume of western red cedar harvested in BC's coast region from 1983 – 2002 is shown in Figure 2 (BC Market Outreach Network 2003a). Based on a five-year average (1997-2001), approximately 6.4 million m^3 of red cedar year is harvested in BC, from all land ownerships. On the coast, an average of 4.8 million m^3/year (1997-2001) is harvested on Crown land (J. Bousquet Personal Communication). Overall the cedar harvest rate has decreased by approximately 12% over the last 20 years. In terms of total coastal harvest, the proportion of cedar has remained substantially the same over the last 20 years at around 24 to 25% (J. Bousquet Personal Communication). The amounts harvested must be within the Annual Allowable Cut, the volume of timber that the Chief Forester determines can be sustainably harvested from the lands regulated by the province. Every five years (or less) there is a timber supply review to ensure this cut is sustainable. This review ensures the annual cut is based on the latest technical information, both economic and environmental The BC Forest Practices Code has mandatory requirements for forest practices and sets enforcement and penalty provisions. Soon after logging, public lands must be reforested with species suited to the site.

To optimally plan the management of western red cedar over the long-term the BC Ministry of Forests is in the process of collating the latest information on inventory, harvest and regeneration of this species. The Ministry has also analysed short- and long-term timber harvesting opportunities for cedar on the coast using a timber supply computer simulation model. Clearcut harvesting is now being phased out on the BC coast. A system called variable retention, which requires retaining enough trees, snags and coarse woody debris, to keep the forest structure intact is now widely practised. This can involve leaving groups of trees intact, or single trees. The degree of retention depends on the designated zoning of the forest. For zones in which the emphasis is on conserving old-growth, most of the trees will be retained.

Growth and Regeneration

An average of about 8.0 million seedlings are planted each year (1991-2002) on the coast which represents about 15% of total coastal planting.

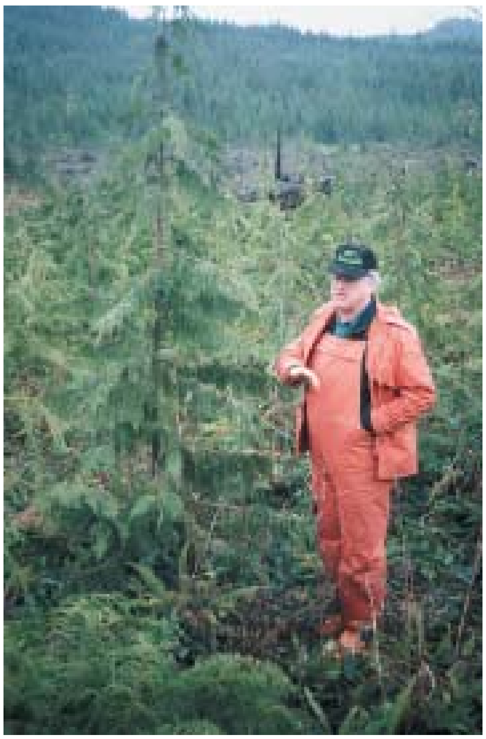
Western red cedar grows best in moist areas or alluvial sites. It tolerates floods well (Krajina *et al.* 1982) and occurs in sphagnum bogs, or in drier but richer soils (Hosie 1969). It is also found in poor sites but with slower growth rates. Optimal growth and development occur in the Olympic Peninsula, Washington (Burns and Honkala 1990). It usually outlives its associates, easily reaching 800 to 1000 years. Some trees have been reported to be more than 3000 years old (Parker 1986).

Western red cedar seldom occurs in pure stands. It is highly shade-tolerant and a major species in coastal climax forests (Sharpe 1974), often present in all stages of forest succession (Burns and Honkala 1990). However, western red cedar's stand dominance has been noted as declining on many sites in coastal British Columbia and Alaska due to poor natural regeneration and slow natural growth rate compared to the current length of forest rotations (Curran and Dunsworth 1988).

A three-year-old red cedar seedling (in north coast BC) with a protective collar to prevent root collar damage by voles.

Seed dispersal and germination are often inadequate for natural regeneration of a clear cut by western red cedar (Curran and Dunsworth 1988). While western red cedar is a prolific and regular seed producer, an overwhelming amount of seed is needed to produce a stand. In addition, there are other critical factors such as seedbed quality, site-specific environmental effects (e.g., temperature, light and moisture regimes), edaphic conditions, competition, smothering, and grazing by small animals that are critical in regeneration (Curran and Dunsworth 1988). These factors have led to a stronger emphasis on planting, although natural regeneration is expected to continue as the most cost-effective alternative for many low-productivity cedar sites (Curran and Dunsworth 1988). The species readily propagates vegetatively. Parker (1986) found vegetative reproduction was more common than seedling reproduction in undisturbed areas in Idaho, Montana and Washington. Survival was best on mineral soil and on rotten wood in contact with the ground.

Artificial regeneration of western red cedar began in British Columbia in the late 1960s in association with other species (Curran and Dunsworth 1988). BC is aggressively replanting cedar. An average of about 8.0 million seedlings are planted each year (1991-2002) on the coast which represents about 15% of total coastal planting (BC Ministry of Forests' Annual Reports). In the 1980s, establishment practices changed emphasis from planting primarily Douglas-fir. The result is expected to be an increase in cedar available for harvest in 70-plus years. In 2002, 30% of the seedlings planted in the Vancouver Forest Region were western red cedar (BC Ministry of Forests' Annual Reports). The trees are typically planted in patches with other species. Cedar is mainly used in wetter areas, in places with root rot pockets and heavy brush, and has been found to be more suited to mild frost pockets than western hemlock or Douglas-fir. A number of ways to maximize the benefits from western red cedar artificial regeneration have been suggested (Curran and Dunsworth 1988). Western red cedar responds well to silvicultural practices such as conifer release, juvenile spacing, precommercial thinning and fertilization (Harrington and Wierman 1985; Minore 1983; Reukema and Smith 1987; Smith 1988). Pure, even-aged stands on upland sites in western Washington can have standing volumes comparable to pure Douglas-fir stands by age 50 years (Oliver *et al.* 1988). On moist sites in western Washington, pure second-growth stands have yielded volumes of up to 825 m^3/ha at age 40 to 60 years. On medium sites in British Columbia, a yield model indicated volumes of 70 m^3/ha at age 40 years, 350 m^3/ha at age 115 years, and 595 m^3 at age 270 years (Burns and Honkala 1990). Maximum current annual increment occurs at 82 years; maximum mean annual increment occurs at 130 years (Burns and Honkala 1990). Diameter and volume growth in 46 to 58 year-old trees in western Washington were negatively correlated with stems/hectare (Nystrom *et al.* 1984). Merchantable yields of western red cedar should be higher in plantation or natural stands with early stocking control.



Dr. John Barker, a silviculture researcher (now retired) examining a 10-year-old planted cedar tree on north Vancouver Island. Dr. Barker was instrumental in establishing many field studies of red cedar over the course of his career.

British Columbia has an active tree improvement program using traditional plant breeding techniques i.e., not "genetically modified". Western red cedar has significant quantitative genetic variation in growth and adaptability (Rehfeldt 1994, Cherry 1995, Russell *et al.* 2003), deer resistance (Vourc'h *et al.* 2002) and wood quality. Much of the variation exists within, and not among, geographic populations. Western red cedar readily self-pollinates (El Kassaby *et al.* 1994, O'Connell *et al.* 2001, O'Connell 2003) and displays minimal inbreeding depression for seed traits and early growth in a nursery (Russell *et al.* 2003) and cold-hardiness (Cherry 1995). After 10 years in field trials, self-pollinated trees displayed a 10% growth reduction, but no difference in survival as compared to outcrossed trees (Russell *et al.* 2003).

A comprehensive gene resource management program is currently under way in British Columbia involving gene conservation initiatives, seed transfer guidelines and tree improvement (Forest Genetics Council of BC 2002). Current seed transfer guidelines are broad (BC Ministry of Forests 1995) and early information from provenance tests indicate more relaxed seed movement in the future (Russell unpubl. data). Approximately 1000 parents are currently being tested in first generation progeny trials, and coastal seed orchards are expected to produce A class seedlots with 10 to 15% volume gain at rotation by the end of the decade (Forest Genetics Council of BC 2002). Seed orchard managers are currently using innovative management techniques to minimise self-pollination (Brown *et al.* 2003).

Western red cedar has shown variability in tropolone extractive content in the heartwood of both old- and second-growth trees. Most of the extractives that contribute to cedar's durability are classed as tropolones (see page 25). As part of the research program approximately 300 parent trees have been assayed for heartwood tropolone concentration and selected parents will be included into a heartwood decay resistant seed orchard (Forest Genetics Council of BC 2002).

Dr. John Russell, a BC forest geneticist specializing in western red cedar in a 4-year-old trial. The trial is set up to examine the growth of the progeny of superior old-growth trees from natural stands.

Western red cedar is considered a desirable tree species for reforestation on many sites because of the following silvicultural attributes: low susceptibility to root rots that infect its close associates Douglas-fir and western hemlock; low number of insect pests; tolerance to wet soils and flooding; and shade tolerance (Curran and Dunsworth 1988). However, compared to western hemlock and Douglas-fir, relatively little is known about the effects of various forest management practices on western red cedar. It has been suggested that research continue in order to further current knowledge on seedling physiology, water relations, nutrition and effects of management practices (Curran and Dunsworth 1988).

Towards Second-growth

Although BC still has a higher proportion of old-growth, second-growth red cedar timber is gradually coming on stream. Along with old-growth, second-growth is now harvested for the high value wood it produces. The USA Pacific Northwest has longer experience with second-growth western red cedar than BC. Marshall and DeBell (2001) state that "*The management of forest resources in the Pacific Northwest has changed greatly since the first harvests of large old-growth trees to the more recent harvests of younger, smaller diameter trees often grown in plantations managed for rapid growth and maximum wood volume. This change continues with an increased emphasis on managing for both wood production and a range of other nontimber values. Our accumulated silvicultural knowledge can help develop regimes to meet these new goals, however, these alternative regimes may produce trees and wood with very different characteristics than in the past. This could have large impacts on value.*" This statement applies increasingly to forestry in BC. Until recently little attention has been placed on the impacts of silvicultural practices on red cedar wood quality. With the emphasis on rapid volume growth it is probable that other characteristics of the trees will change, and not necessarily favourably in terms of wood quality.

"*Western red cedar is one of the most shade-tolerant trees species of the Pacific Northwest. In the future western red cedar will play an increasingly important role in alternative management schemes to broaden species composition and enhance structural diversity in managed stands*" (Marshall and DeBell 2001).

Second-Growth Red Cedar Quality Remains High

Vertical radial sections from a 386-year-old (middle, radius 28 cm) and a fast grown 71-year-old (bottom, 19 cm) cedar tree. The horizontal radius of the older tree is also shown (top). The numbers indicate the number of annual rings from the heartwood/sapwood boundary. Chemical analysis for total β- and γ-thuaplicin content showed similar amounts for both trees, both thujaplicins being highest in the outer heartwood and lowest close to the pith.

The extractive content, and therefore durability, appears to be high in rapidly-grown trees.

Future logs, whether for commercial use or to perform as ecologically important persistent wood debris will come from managed young-growth stands. Maintaining the durability of that wood is of concern. Work is on-going both in BC (Russell 2003) and in the US (Marshall and DeBell 2001) to investigate some of the interrelationships between growth rate, wood density and wood durability under different silvicultural regimes. The data show that faster grown cedar is lower in density than old-growth, which is probably inconsequential given that the major uses of western red cedar are non-structural Unexpectedly the extractive content appears to be high in rapidly grown trees. Marshall and DeBell 2001 suggest that wood with high extractive content can be produced via silvicultural practices designed to enhance growth and yield in young managed stands (see p 23-24).

Diseases, Insects and Other Damaging Agents

Western red cedar is attacked by a number of insects, fungi, and mammals, but only a few of these cause significant problems in natural stands and plantations (van der Kamp 1988). Western red cedar's resistance to damaging agents is the highest among native tree species (Krajina *et al.* 1982). In recognition of this it is exempt from European plant-health regulations concerning the import of softwood lumber from North America.

Diseases

Stem diseases: There are no major diseases of the stems but several minor fungi occur on weakened or dead stems. A list of these fungi is given by Minore (1983).

Cedar leaf blight (Keithia disease) caused by *Didymascella thujina* (Durand) Maire can cause nursery seedling mortality (Kope *et al.* 1996), defoliation and reduced growth in young trees, and in severe cases, tree mortality (van der Kamp 1988) and plantation failure. Keithia disease can occur on all western red cedar trees, and has been shown to be regulated by a single dominant gene (Soegaard 1969). The degree of infection caused by Keithia disease is related to population origin, with coastal, low elevation populations being more resistant (Lines 1988, Russell *et al.* 2003) and displays significant tree-to-tree variability with narrow-sense heritabilities greater than 0.3 (Russell *et al.* 2003). Severe infestation could cause mortality (van der Kamp 1988), but epidemics are rare in North America (Minore 1983).

A 10-year-old provenance trial plantation which has Keithia disease. This is a common disease in low elevation coastal plantations.

Canker diseases of the bark are rare and bark-killing organisms are restricted to stressed or damaged trees (van der Kamp 1988).

Trunk rots: The heartwood of western red cedar is resistant to decay due to the fungitoxic nature of its main extractives, the thujaplicins (see p 23-26). In spite of this, decay is extensive in old living trees (van der Kamp 1988). This was attributed to the detoxification of heartwood from the centre outwards through the successive invasion of fungi, each of which alters the chemical nature of the wood (Jin 1987; van der Kamp 1986). Cedar also lives to a greater age than most other conifers. Hence there is more time for decay to develop. Initially, non-decay fungi (tentatively identified as *Sporothrix*) in the sound heartwood degrade the toxic extractives into non-toxic compounds (Jin *et al.* 1988). This action paves the way for invasion by other fungi (*Kirsteiniella thujina and Phialophora sp.*), which in turn facilitate further invasion by decay fungi such as *Ceriporiopsis rivulosa* (Berk & Curtis) Gilb. & Ryvarden which causes white laminated rot (Allen *et al.* 1996). The heartwood surrounding columns of decay is always dark brown (Jin *et al.* 1988).

> *Western red cedar's resistance to damaging agents is the highest among the native tree species*

Butt and root rots: *Armillaria ostoyae* (Romagn.) Herink can girdle and kill young trees quickly; older trees are not readily killed (van der Kamp 1988). *Poria subacida* (Peck) Sacc. has caused extensive damage in pole-sized trees with the source of the fungus being infected stumps left from thinning (van der Kamp 1988). In the BC interior, a common butt-rot fungus is a form of *Phellinus weirii* (Murr.) Gilbn. which can cause decay in young trees. Severe losses have been associated with "included sapwood", a light coloured band within the heartwood. This included sapwood is low in extractives and is readily invaded.

A more extensive list of decay fungi found in trunk rots is given in the literature review by Minore (1983) and a more extensive list of diseases of cedar is given by Allen *et al.* (1996).

Insects

Insects cause little damage to western red cedar trees but occasionally cause problems (Burns and Honkala 1990; Minore 1983; van der Kamp 1988). Among most damaging are:

i) *Mayetiola (Phytophaga) thujae* Hedlin), a cone midge which sometimes infests 100% of the cones and seriously damages western red cedar seeds in Oregon, Washington, and British Columbia (Furniss and Carolin 1977; Minore 1983; van der Kamp 1988).

ii) Bark beetles of the genus *Phloeosinus (P. punctatus* LeConte and *P. squamosus* Blackman) which attack severely stressed trees and have been reported to sometimes cause mortality (Furniss and Carolin 1977; Minore 1983).

iii) Wood borers: the flatheaded western cedar borer, *Trachykele blondeli* Marseul, a buprestid beetle, is common in south-coastal BC and attacks healthy, living trees (McLean 1998). The adults feed on foliage and deposit eggs under bark scales. The larvae bore from the branches into the bole and the tunnels cause degrade and cull in some trees (Duncan 1995). Some geographic forest areas are especially subject to damage by this insect (Furniss and Carolin 1977; van der Kamp 1988). Two roundheaded borers, *Atimia confusa* Say and *Semanotus amethystinus* LeConte, attack the bole and branches of large western red cedars but are restricted to recently dead or dying trees (Furniss and Carolin 1977; van der Kamp 1988).

iv) Ambrosia beetle (*Gnathotrichus sulcatus* LeConte) forms small galleries surrounded by blue stain, resulting in degrade (Furniss and Carolin 1977; van der Kamp 1988). These beetles only attack logs or weakened trees. Note that these insects are not carried by western red cedar lumber, nor do they damage lumber products.

Other Damaging Agents

Deer and elk browse red cedar seedlings and saplings, and this is one of the largest obstacles to regenerating red cedar. Black bears remove the bark and feed on the exposed sapwood (Minore 1983; Sullivan 1992). Domestic animals like cattle and sheep have also been known to browse red cedars in Oregon and Idaho (Minore 1983). Because of its shallow root system and thin bark, western red cedar is readily killed by fire (Harlow *et al.* 1979).

THE RAW MATERIAL

The uniform texture is due to the earlywood zone comprising almost the entire ring width in both old (bottom) and young (top) trees.

Gross Physical Features of the Wood

The sapwood is white with a slight yellow tinge (Panshin and DeZeeuw 1970). The heartwood is variable in colour, ranging from light straw to various shades of pinkish or reddish brown to deep warm brown (Harrar 1957). The unprotected wood turns to a dark lustreless grey or brownish grey when exposed to the elements. It is generally straight-grained, uniformly coarse in texture, non-resinous, with a characteristic sweet aromatic odour and faint bitter taste. The uniform texture is due to the earlywood zone comprising almost the entire ring width. The growth rings are distinct, sharply delineated by narrow bands of dark brown latewood. The transition from earlywood to latewood is fairly abrupt in narrow-ringed wood and rather gradual in wide-ringed material (Harrar 1957).

Sapwood

The sapwood of western red cedar is usually narrow, averaging from 18 to 43 mm over a wide range of tree ages and diameters, and generally increases with tree diameter (Lassen and Okkonen 1969). Wellwood and Jurazs (1968) studied 73 trees and found the average width to be 22 mm, maximum at stump height and minimum at about 5 m from the stump, after which it increased with height in the stem. However, this increase was only 5 mm over a height increase of 40 metres.

Western red cedar sapwood has an average green moisture content of 249% compared to 58% in the heartwood (based on the oven-dry weight of the wood) (Nielson *et al.* 1985). The sapwood is fairly permeable to chemical preservatives, an important characteristic for cedar utility poles requiring preservative treatment of the non-durable sapwood for longer service life.

Heartwood

Permeability

Western red cedar heartwood is highly impermeable to water and water-borne chemicals. This condition is attributed to crusty deposits in the membrane of bordered pits (tracheid openings that allow the passage of fluids), thus impeding the inter-tracheid fluid movement (Krahmer and Cote 1963) and resisting fluid penetration of the wood. Heavy deposits were noted in the heartwood, but were also present in the sapwood in lesser amounts (Krahmer and Cote 1963).

Colour Variations

The heartwood of mature western red cedar can exhibit wide variations in colour. The patterns of discolouration are different for the coastal and interior British Columbia cedar. In butt logs of mature trees from the coast it is quite common to find a central core of brown rot in which the colour shifts from dark brown in the innermost wood, through brown and pinkish brown toward the periphery. The various colour zones have distinct but irregular boundaries, and can be visualized as a set of "irregularly shaped nesting cones with sides that are roughly parallel to the cambium in longitudinal but

Cross-section of western red cedar showing the "archery target" pattern, an unusual type of colour variation found in some interior areas of British Columbia and northwestern United States. (Disk supplied by Pope & Talbot, Grand Forks, BC)

not in transverse section" (van der Kamp 1986). Frequently, the light straw coloured heartwood occurs as a wide outer band (from a few cm to more than 25 cm wide) and should not be confused with the narrow band of almost-white sapwood. MacLean and Gardner (1956) have shown that the thujaplicin and hot-water solubility contents of the dark brown inner heartwood are much lower than that of the outer straw coloured heartwood. Kai and Swan (1990) analyzed the chemical constituents contributing to the colour of western red cedar heartwood and suggested that the colouring material is formed from lignans such as plicatic acid by a condensation reaction with acid catalyst.

There are two unusual types of colour variation found in western red cedar which exhibit a different chemical distribution: the "archery target" pattern and the "oil" or "resin streaks". The "archery target" pattern is common in some interior areas of British Columbia and northwestern United States. It consists of alternate concentric bands of light and brown coloured wood when viewed on the cross-section. In some trees, the bands are only arcs of circles and not complete rings, and while they tend to follow the annual rings, they sometimes cross over growth rings. The light coloured band resembles sapwood and is sometimes referred to as "included sapwood" because it is chemically more similar to normal sapwood than to heartwood. The "included sapwood" has low extractives content and similar natural decay resistance as the normal sapwood (MacLean and Gardner 1958).

The other unusual type of colour variation in western red cedar, "resin streak", consists of narrow bands of very dark wood along the grain. The streaks have a slightly resinous appearance and are heavily infiltrated with light brown extractives which could be as much as 30 to 50% of the wood weight (Barton and MacDonald 1971). Since western red cedar has no resin canals, this resinous material may partly be the result of injury to the tree.

Over the years, scientists have tried to explain the cause of colour variations in western red cedar heartwood and relate it to decay resistance. Early studies (Eades and Alexander 1934; Findlay and Pettifor 1941) have shown that the dark coloured inner heartwood was inhabited by a number of fungi while the outer straw coloured heartwood was virtually sterile. Barton and MacDonald (1971) suggested that the cause of colour variation may be the result of chemical changes induced in extractives by the enzyme systems of microorganisms which may not necessarily be of the wood-destroying type. Van der Kamp (1986) noted that the inner stained heartwood of a 300+-year-old western red cedar tree had a lower thujaplicin and hot-water soluble extractive content than the outer heartwood, but their decay-

A creative use of the natural colour variation in western red cedar.

resistance was not significantly different. He attributed this to the presence of a fungitoxic thujaplicin derivative in the inner heartwood. Jin (1987) and Jin *et al.* (1988) later found a higher natural decay resistance in the outer straw coloured zone of the heartwood than in its inner dark coloured zone. The authors confirmed that the heartwood discolouration was the result of a degradation process brought about by the successive action of fungi within the heartwood, from the centre outward. During this process, thujaplicin is degraded into non-toxic compounds which facilitate the subsequent invasion by decay fungi.

Findlay and Pettifor (1941) related the dark colouration of the heartwood to its mechanical properties and found that it had about 20% lower relative density, toughness, and compression strength properties than the normal light coloured heartwood.

Bark

The outer dead bark of western red cedar is fibrous and forms a closely interlacing network. Vertical resin canals, usually several millimeters long, are present in both the inner and outer bark. Bark fibres are about 2.5 to 3.0 mm long. The double bark thickness measured on a total of 170 coastal and interior-grown trees, ranging in age from 73 years to 489 years, averaged 19 mm for all sections, with an extremely high coefficient of variation of about 60% (Smith and Kozak 1967). The basic relative density of the inner and outer bark was 0.36 and 0.38 respectively; the moisture content was 88% and 37% (oven-dry basis), respectively (Smith and Kozak 1971).

The bark forms flat narrow ridges on old trunks.

The chemical nature of cedar bark has been studied extensively (Barton and MacDonald 1971). It has been found to contain many complex substances including tannins, phlobaphenes, vanillin, catechin and fatty acids among others. A chemical analysis of the bark showed that it contains 31% lignin, not all that different from the lignin content of the wood (Isenberg 1980). Soda pulping of the bark in various stages of solvent extraction showed that removal of the extractives did not improve pulp yield or facilitate the removal of a residual lignin resistant to solubilization (Swan 1966).

Debarking cedar logs is more difficult than with other species because cedar bark is stringy and forms into balls in mechanical barkers, conveyors and hogs. However, cedar bark on wood chips will bleach in the kraft pulping process and will not produce dirty specks that contaminate the pulp (McWilliams 1988).

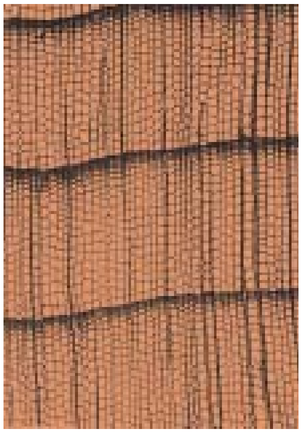
Cedar bark is not suitable for landscape and horticulture purposes because its acidic extracts damage the root system of plants (Steer 1995) and its stringy nature creates handling problems.

The heating value for western red cedar bark is 20.24 MJ/kg or 8700 BTU/lb (Nielson *et al.* 1985).

Microscopic Features of the Wood

Cross-section: normal resin canals are absent. Longitudinal parenchyma cells (thin-walled cells with dark contents) are sometimes sparse but when present in greater quantities, they are usually confined to the latewood zone and may be visible with a hand lens as a broken tangential line. Transition from earlywood to latewood is usually abrupt.

Cross-section of western red cedar showing the narrow latewood



Radial section (vertical grain): paired bordered pits are common on the radial walls of earlywood tracheids. Cross-field pits (pits leading to ray parenchyma) are oval, quite uniform in size, with distinct border and lenticular orifice (having the shape of a double-convex lens), usually 1 to 4 per cross-field. Rays are usually less than 7 cells high, consisting of pure parenchyma cells; ray tracheids are rare on the upper and lower margins. Ray cells have smooth end walls with indentures, and scanty gummy infiltrations (Panshin and de Zeeuw 1970).

Tangential section (flat grain): the rays are uniseriate (i.e., one-cell wide). Sporadic pitting is present but only in the last few rows of latewood tracheids.

The tracheids have an average fibre length of 3.5 mm (1.4 to 5.9 mm) and an average tangential width of 30 to 45 µm (Isenberg 1980). Wellwood and Jurazs (1968) found tracheids to be shorter near the pith (1.2 mm), reached a length of 3.5 mm at 50 years, and increased slowly for an indefinite period thereafter. Fibre length was found shortest at stump height, longest at mid-height, and did not change appreciably with height position in the stem thereafter. By excluding stump and all samples younger than ten years, an arithmetic average fibre length of 3.3 mm was obtained, decreasing to 2.3 mm when all samples were considered. Graff and Isenberg (1950) found the average fibre length of kraft pulp to be shorter, 2.05 mm, most likely because of breakage.

The bordered pit membrane has no torus (the thickened central portion of the pit membrane). The membrane consists of closely packed strands heavily covered with incrustations, more so in the heartwood than in the sapwood. The openings between the strands are about 0.1 µm, and are much smaller than those in Douglas-fir or western hemlock (Krahmer and Cote 1963).

The wood of western red cedar is similar to and often confused with that of eastern white-cedar, incense-cedar and redwood (*Sequoia sempervirens* (D.Don.) Engl.). Their colours intergrade and the difference in their odours is very subtle. Western red cedar and incense cedar have similar spicy aromatic odor; eastern white-cedar has a faint but characteristically "cedar odor". Microscopically, however, incense-cedar is different. Its ray cells have nodular end walls and gummy contents, and are biseriate in part (i.e., two ray cells wide as seen on the tangential surface). Microscopically, eastern white-cedar is very similar to western red cedar. They are more readily separated by gross features: eastern-white cedar is not as dark as the average shade of brown in western red cedar, has finer texture, and usually has a more gradual transition from earlywood to latewood. Because these species grow in very different geographic areas, information on their origin could help separate them.

Physical Properties of the Wood

Relative Density and Weight of the Wood

The wood of western red cedar is light. Based on its oven-dry weight and green volume density of 330 to 340 kg/m^3, the weights of western red cedar that can be expected at other moisture contents have been calculated and presented in Table 2. The wood weighs 370 to 385 kg/m^3 when air dry (12% moisture content), 330 to 340 kg/m^3 when oven-dry, and 432 to 533 kg/m^3 when green (Isenberg 1980; Jessome 1977; Mullins and McKnight 1981; Nielson *et al.* 1985; Rijsdijk and Laming 1994; USDA 1955).

TABLE 2.
Weight of western red cedar wood calculated for different moisture contents (MC)

% MC	0 Oven Dry	6	9	12 Air Dry	15	30	60 Green
Weight (Kg/m³)	330-340	350-360	360-371	370-385	380-391	429-442	528-544
(Lbs/ft³)	21	22	23	23.5	24	27-28	33-34

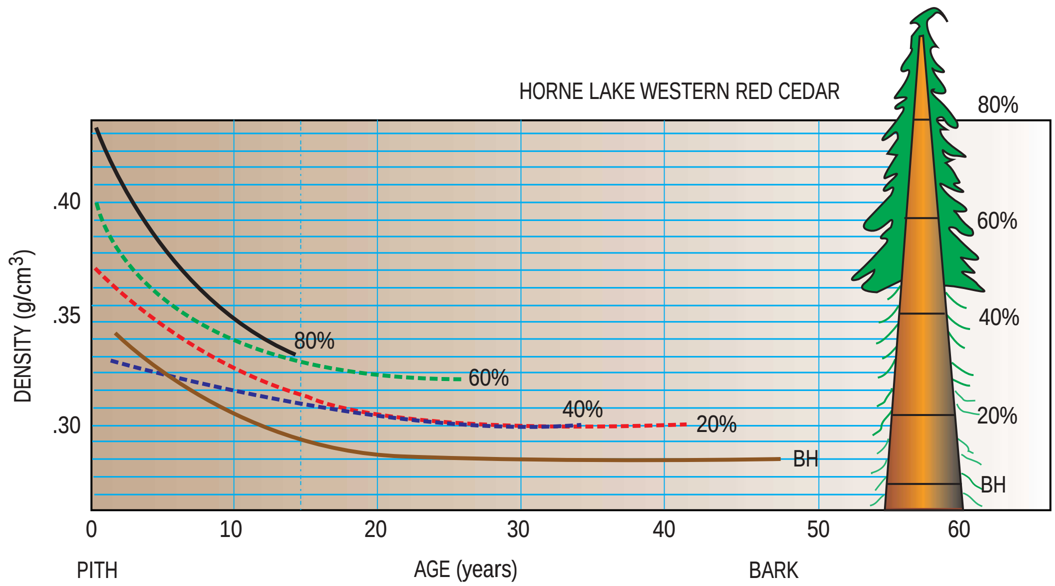


FIGURE 3.
Basic density profile of fast-grown 50-year-old western red cedar from pith to bark at various heights on the stem (average of 5 trees) (after Jozsa and Kellogg 1986)

The average relative density (specific gravity) of western red cedar in British Columbia is about 0.33 based on oven-dry weight and green volume (Smith 1970). Jessome (1977) gives a lower average value of 0.31 based on 12 trees. Cown and Bigwood (1979) obtained mean basic densities of 315 to 341 kg/m³ for trees grown in New Zealand.

The relative density of western red cedar increases with height in the stem but decreases radially from the pith, rapidly during the first five years of growth, followed by a more gradual decrease until about the 20th year, and levels out thereafter (Figure 3) (Jozsa and Kellogg 1986; Okkonen *et al.* 1972; Wellwood and Jurazs 1968). It appears (from Figure 3) that juvenile wood in western red cedar includes the first 20 rings from the pith and has higher density than the mature wood. Wellwood and Jurazs (1968) found density to decrease further after the 100th ring in a 250-year-old tree.

Smith (1980) examined the influence of spacing on the radial growth and latewood percentage of 21-year-old western red cedar trees. He found ring widths increased and percentage latewood decreased with increased spacing. Although density was not measured, one could deduce from these results that wider spacing reduces wood density. Smith

Western red cedar is one of the most dimensionally stable of all softwoods.

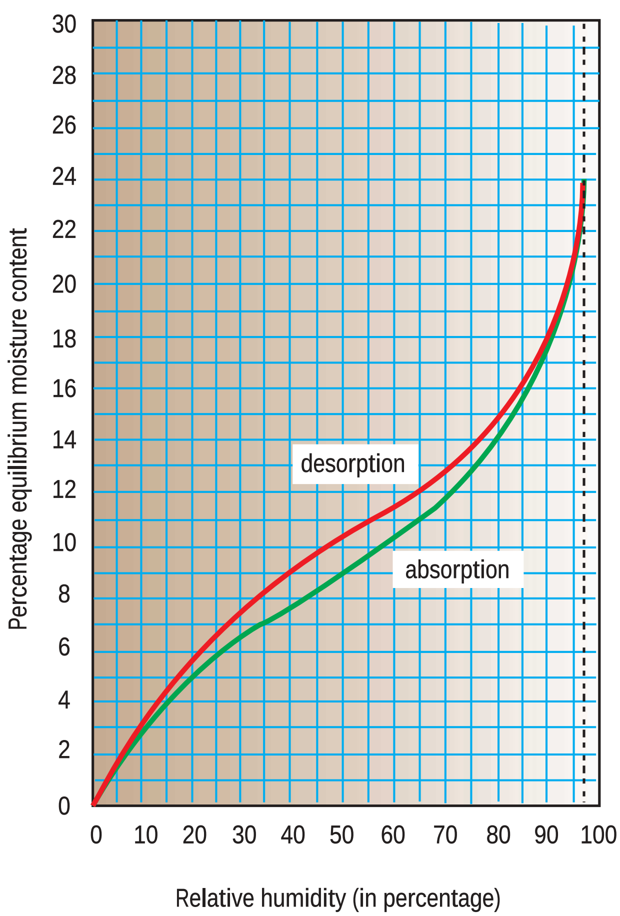
and Parker (1978) found earlywood relative density (by x-ray analysis) ranged from 0.25 to 0.32; latewood density, from 0.51 to 0.69; and ring density, from 0.26 to 0.36.

Dimensional Stability

Western red cedar wood has excellent dimensional stability because of its low wood density and low shrinkage factor. A major contributor to its dimensional stability is the fact that its moisture content at the fibre saturation point is 18 to 23%, compared to 25 to 30% in most Canadian softwoods (Higgins 1957; Rijsdijk and Laming 1994). As a result, western red cedar shrinks and swells minimally, displaying small movements with changes in humidity (Figure 4) (Rijsdijk and Laming 1994). Lower absorption of water is a result of the high extractive content blocking absorption sites. The ability of western red cedar to resist moisture absorption is illustrated by the data in Figure 5. This shows the moisture content of dry western red cedar compared to samples of Douglas-fir, western hemlock and Sitka spruce left covered, outdoors, over a one-year period. The initial drying was to 6 to 10% moisture content. In two months the cedar samples equilibrated in the range 9 to 11% where it remained over the period of the test, fluctuating slightly with changing relative humidity. Douglas-fir was in the range of 12 to 16% while spruce and western hemlock ranged from 14 to 20-21%. The fluctuations shown on the graph

FIGURE 4.

Hysteresis, shrinkage and swelling curves of western red cedar (average values of 15 test specimens from 11 trees) (after Rijsdijk and Laming 1994)



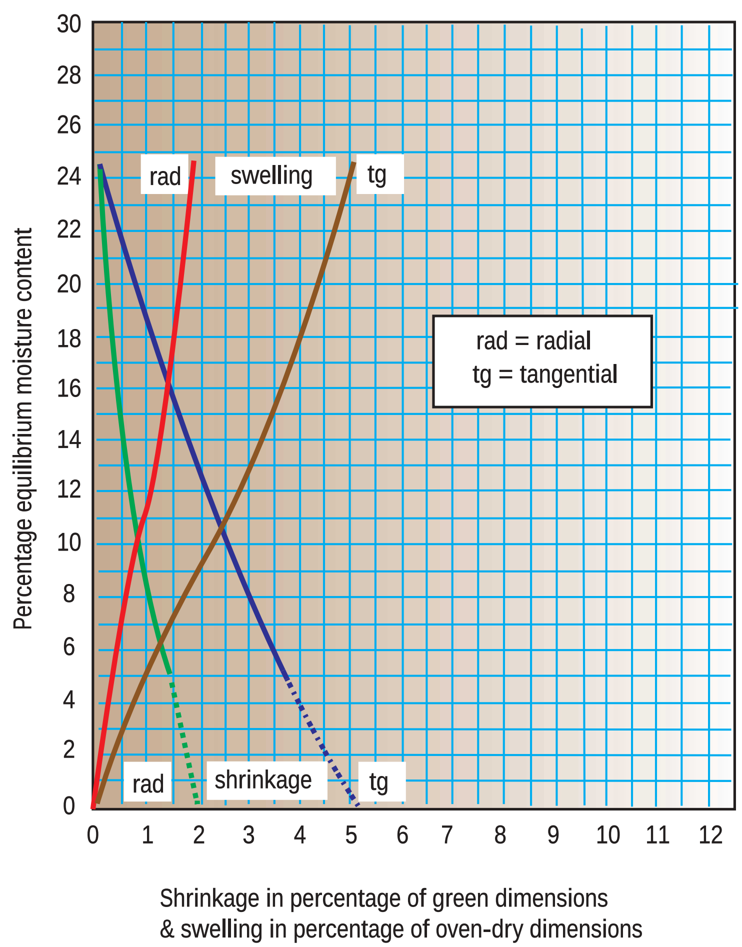


FIGURE 5.

Moisture content of western red cedar exposed to outdoor air compared with three other softwoods. (Unpublished Forintek data)

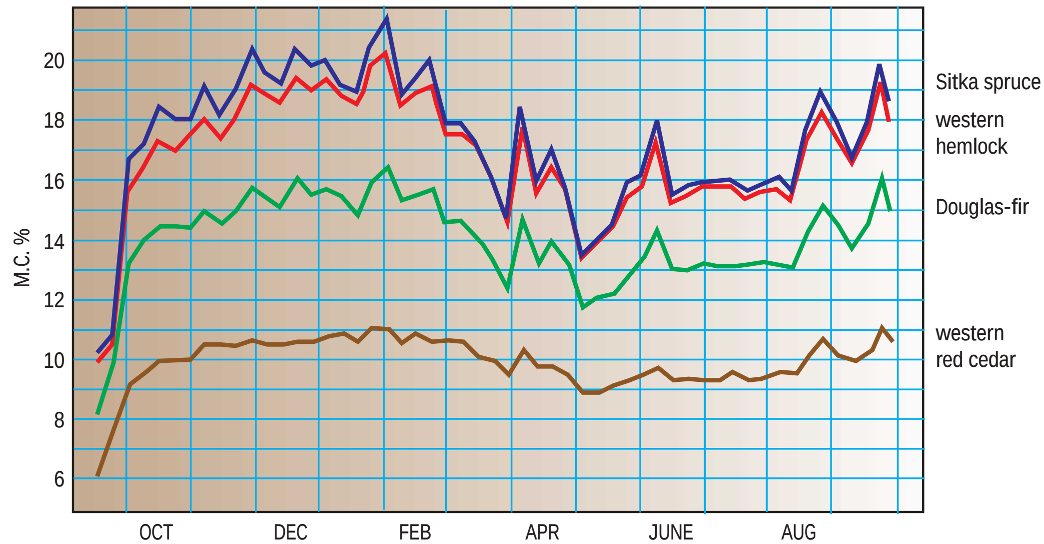


TABLE 3.

Average percentage shrinkage of western red cedar from green to various moisture contents (based on green dimension) reported by various authors.

Percent Moisture	Percent Shrinkage, Based on Green Dimensions			
	Radial	Tangential	Volumetric	Longitudinal
0	2.1[a]	4.5[a]	7.8[a]	-
	-	-	-	0.19[b]
	-	-	-	0.15[c]
	-	-	-	0.53[d;e]
	-	-	-	0.40[d;f]
6	1.9[g]	4.0[g]	5.4[g]	-
12	1.2[h]	2.6[h]	4.8[a]	-
15	0.96[g]	2.0[g]	-	-
20	0.8[g]	1.7[g]	2.3[g]	-

a Jessome 1977 (12 trees, B.C., old-growth)
b Rijsdijk and Laming 1994 (35 test pieces; B.C. and U.S.A.)
c Espenas 1974 (54 test pieces)
d Nault 1986 (5 trees, B.C., second-growth)
e Innermost juvenile wood
f The first 70 rings from the pith
g Harrar 1957
h WRCLA 1992

will translate into dimension changes for the wood. The smaller fluctuations with red cedar represent superior dimensional stability, a desirable trait for wood that gets alternatively wet and dry such as roofing, siding, decks and garden accessories. This property contributes to western red cedar's suitability for these and other uses where dimensional stability and water repellency is important. The wood is superior in resisting warp or twist from its fastenings (Harrar 1957) although hair-line surface checks may develop on unprotected surfaces when exposed to the elements.

The shrinkage values of western red cedar from green to various moisture contents are presented in Table 3. The values for longitudinal shrinkage obtained by Nault (1986) on juvenile wood are much higher than those reported for mature wood by Rijsdijk and Laming (1994) and Espenas (1974). This is probably because Nault's measurements were done on juvenile wood which is characterized by high shrinkage.

Thermal and Insulating Properties

Western red cedar has a flame spreading rate and a smoke developed classification that are considerably below the maximum limits set by US and Canada Building Codes.

Western red cedar has good insulation value because of its low wood density and coarse texture. It is the best insulator among the most common available softwood species and is far superior to brick, concrete and steel. Its coefficient of thermal conductivity (k) is 0.11 W/m °C (or 0.74 BTU in./ft^2 h °F) at 12% moisture content (USDA 1952). Conversely, because of its low density, western red cedar has a faster charring rate (about 0.8 mm/min) than a denser wood like Douglas-fir (which has a charring rate of about 0.6 mm/min) under dry conditions (Lie 1992). The charring rate is the linear rate at which wood is converted to char. The higher charring rate of cedar is regarded to be of minor importance (J. Mehaffey Personal Communication).

The flame-spread rating of western red cedar is 67 to 73 (Class II rating) (Richardson 1996) and the smoke developed classification is 98 (WRCLA 2001). Both of these are used to regulate the use of materials where potential to generate smoke or smoke control movement is important. The flame-spread rating is a measure of the rate of advance of flame along the surface of wood. Canadian and US codes set the maximum flame-spread rating for interior wall and ceiling finishes in most buildings at 150 (National Building Codes Canada 1995). Since western red cedar has a low flame-spread rating, it will perform better than most dense softwoods which have flame-spread ratings around 100. The Canada National Building Code (1995 Article 3.1.13.2) restricts the flame-spread rating of walls in some occupancies to 75 or less. Western red cedar would be one of very few solid wood products that would be acceptable for these.

The smoke-developed classification reflects the amount of smoke released by a burning material. The maximum set by Canadian and US codes for smoke-developed classification for interior wall and ceiling finishes in high-rise buildings are 300 and 450, respectively. Thus, western red cedar has a flame spreading rate and a smoke-developed classification that are considerably below the maximum limits set by US and Canada Building Codes.

The heating value for western red cedar wood is 22.56 MJ/kg or 9700 BTU/lb (Nielson *et al.* 1985).

Finishing and Workability

The wood takes a variety of coatings, paint and stain, exceptionally well, when dried and properly primed (Williams *et al.* 1987). It glues well with a wide range of adhesives and gluing conditions. The wood is among the easiest to work with because of its straight grain and uniform texture. It planes and sands cleanly (WRCLA 2001), and because of its low wood density, it requires little energy to saw or otherwise work.

Unseasoned western red cedar is extremely corrosive to metals; chemical wear of saws results from chelation of metal by polyphenolic and tropolone compounds in the wood. The use of chemical and wear-resistant Stellite tips on the saw teeth is recommended (Kirbach and Bonac 1977; Kirbach 1992). The corrosive nature of western red cedar extractives (the thujaplicins and polyphenols) require the use of corrosion-resistant nails and screws (e.g., stainless steel, hot-dipped galvanized, and high tensile-strength aluminum) for fastening western red cedar. Used outdoors non-resistant nails such as common iron wire and copper nails rapidly deteriorate and decompose, accelerating the oxidative deterioration of wood around the nails. In a year or so, holes appear where the nails used to be. This phenomenon is common in shakes and shingles where common steel nails are used. Hot-dipped galvanized or stainless steel nails should always be used with red cedar that might get wet.

Hot-dipped galvanized, stainless steel or high tensile-strength aluminum nails are recommended for use with western red cedar.

When cutting green western red cedar with a bandsaw, excessive surface roughness can occur due to fibre pulling as a result of bond failure between individual fibres. Up to 10% of rough-sawn siding and panelling products may be downgraded or rejected as a result (Kirbach 1996). An exploratory study showed that varying the angle between grain and cutting direction could reduce the problem (Kirbach 1996).

The wood has low nail-, screw-, or bolt-holding capacity, thus requiring about one-third longer or larger diameter fastenings than hardwood species (WRCLA 2001). The use of common wire and copper nails should be avoided because western red cedar wood is susceptible to discolouration when iron or copper chelates form with thujaplicins or plicatic acid in the wood (Barton and MacDonald 1971).

The ease of splitting red cedar is an advantage in the manufacture of handsplit shakes, but a drawback when trees are felled on rough terrain and handled with heavy machinery. Under these circumstances, breakage, splitting and shattering could be severe (McBride 1959).

Western red cedar's ability to damp vibrations is an important acoustical property that makes it particularly effective for use as panelling and decking to help reduce or confine noise (WRCLA 2001). Conversely the superb acoustic resonance properties of thin edge-grain western red cedar make it a good choice for musical instruments.

The wood takes a variety of coatings, paint and stain exceptionally well.

Western red cedar's ability to damp vibrations is an important acoustical property that makes it particularly effective for use as panelling and decking to help reduce or confine noise.

Drying Properties

Wood should be dried to approximate the moisture content it will equilibrate to in service. This will depend on the ambient relative humidity of the air (see Figure 5). Indoors the equilibrium moisture content would normally be about 6 to 8%. Western red cedar is kiln-dried for finish, shop, panelling, and siding lumber (Mackay and Oliveira 1989). The lumber is generally easy to dry with very little degrade, but "may prove very difficult to dry in the thicker sizes" (BRE 1977). Most schedules use conventional or low temperatures, or a combination of conventional temperatures with subsequent change to high temperatures (Mackay and Oliveira 1989). Salamon and Hejjas (1971) showed that western red cedar lumber could be dried with low-high temperature combination schedules without causing critical strength or degrade loss. Avramidis *et al.* (1994) examined the use of radio-frequency/vacuum drying with constant voltage on western red cedar. They established that thick samples (9.1 cm by 9.1 cm in cross-section) could be dried in a field strength of 1.8 kv/m without degrade.

Collapse and Honeycomb

In some circumstances western red cedar can be prone to collapse during drying and for this reason wider and thicker pieces have to be dried carefully. Collapse is the caving in of the wood surface due to the severe distortion of some cells in the wood (Mackay and Oliveira 1989). It is generally attributed to water tension forces developing within completely saturated cells during drying conditions when moisture passes out through the cell walls and no air can take its place (Guernsey 1951). The internal force is strong enough to cause the cells to break down or collapse, especially if the wood is plasticized during high-temperature drying.

Meyer and Barton (1971) related collapse formation to high initial moisture content and extractives of the wood, but offered no definitive explanation on the actual mechanism involved. Kobayashi (1985) studied the anatomical structure of collapsed wood using a scanning electron microscope and found crushed tracheids and distorted latewood. He suggested that earlywood tracheids crushed first and developed into a distorted layer that caused buckling of the latewood zone. In circular cross-sections, the crushed tracheids occurred concentrically near the surface and parallel to the annual rings in the core during hot-air drying. Collapse and crushing did not occur when drying was accomplished under vacuum with the microwave method, suggesting that collapse occurs from drying stresses caused by the moisture gradient during drying (Kobayashi 1986).

Collapse occurs during the initial stages of drying (Mackay and Oliveira 1989) when moisture contents are high (probably above 50% MC). Thus it differs from normal shrinkage which begins at the fibre saturation point. Collapse-prone lumber should therefore either be air-dried first to allow a gradual drop in moisture content, or kiln-dried at a low dry bulb temperature of about 120°F, to fibre saturation point, and then kiln-dried at normal temperatures (Guernsey 1951; Mackay and Oliveira 1989).

Guernsey (1951) noted that logs from low, swampy ground produced boards susceptible to collapse. This is nearly impossible to predict from the appearance of the log or green lumber.

TABLE 4.
Chemical components of western red cedar compared to those of western hemlock and Douglas-fir wood (values are expressed as a percentage of moisture-free weight of wood)*

Species	Alpha-cellulose	Hemicelluloses	Lignin	Total Extractives	Ash
Western red cedar	47.5	13.2	29.3	10.2	0.2
Western hemlock	48.8	14.7	28.8	5.3	0.5
Douglas-fir	53.8	13.3	26.7	5.9	0.3

* Lewis 1950

TABLE 5.
Chemical composition of medium growth-rate western red cedar heartwood and sapwood at three height positions in the tree (moisture-free wood basis)*

Sample	Holocellulose	Lignin	Total Extractives**	Ash
Heartwood:				
Butt	56.5	29.0	15.4	0.32
Middle	59.0	28.1	14.9	0.14
Top	62.2	28.3	11.1	0.24
Sapwood:				
Butt	67.1	32.3	3.6	0.54
Middle	66.8	31.4	4.4	0.45
Top	66.1	29.8	5.0	0.33

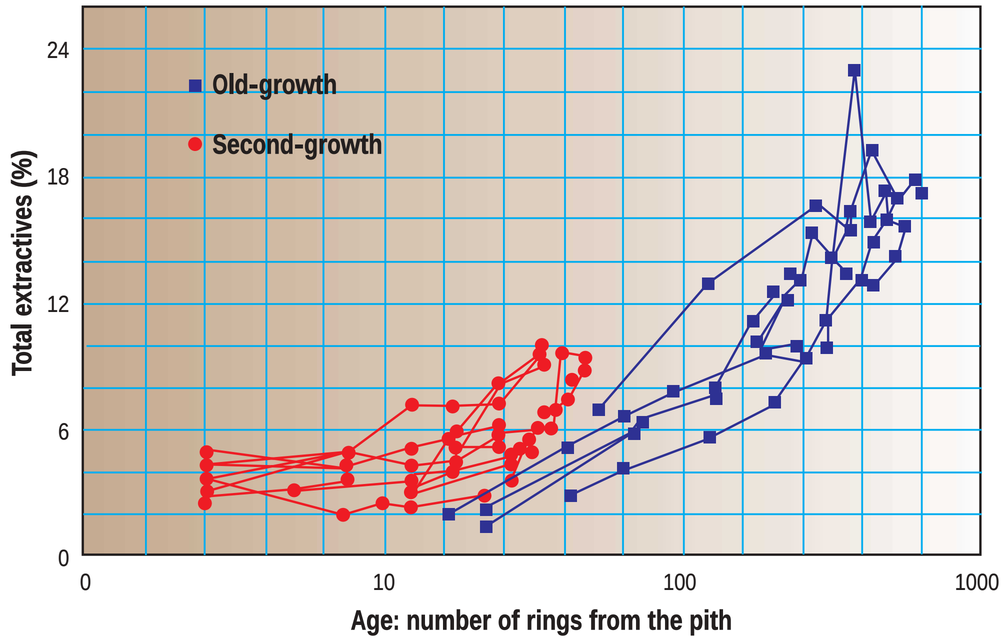
*Barton and MacDonald 1971
**Successive solubility in ethanol-benzene, ethanol and hot water

Chemical Properties

The main chemical constituents of western red cedar wood, namely cellulose, hemicellulose, and lignin, occur in about the same proportion as they do in most other softwoods. Holocellulose and lignin contents are lower in the heartwood than in the sapwood. Extractives, which are considered extraneous chemicals that can be extracted from the fibrous structure by water or other solvents (Nearn 1955), are high.

The heartwood extractives content stands out as unusually high. Lewis (1950) showed that the total hot water extractives in western red cedar were almost twice as much as in western hemlock and Douglas-fir (Table 4). The total heartwood extractives decreased from butt to top (Table 5) (Barton and MacDonald 1971).

FIGURE 6.
Percent total extractives in old- and second-growth western red cedar (after Nault, 1988)



Extractives

The extractives of western red cedar heartwood distinguish it from that of the other softwoods in colour, odour and taste. They affect western red cedar's decay-resistance, corrosiveness, permeability, paintability, pulping and bleaching properties far out of proportion to the amounts present (Barton and MacDonald 1971). Because of their importance to western red cedar utilization, the heartwood extractives have been extensively studied by several researchers (Barton and MacDonald 1971; Jin *et al.* 1988; MacLean 1970; MacLean and Gardner 1956; Minore 1983; Nault 1988; Swan *et al.* 1988; van der Kamp 1986).

The extractives obtained by hot water extraction are readily separated into volatile (1.0 to 1.5% of the heartwood) and non-volatile fractions (5 to 15%) by steam distillation (Barton and MacDonald 1971). The volatile fraction consists mainly of the thujaplicins, thujic acid and methyl ester. The thujaplicins, in particular, and thujic acid, to a lesser extent, are excellent natural fungicides. The thujaplicins are highly toxic to wood- destroying fungi; their toxicity being of the order as that of sodium pentachlorophenate (Barton and MacDonald 1971). Methyl thujate is one of the extractives responsible for the characteristic odour of western red cedar and has some toxicity to the carpet beetle and case-making clothes moth (Barton 1962). For this reason western red cedar is a preferred wood species for lining blanket chests.

The amount of thujaplicins and water-soluble phenols in the heartwood increases radially from the pith but is negligible in the sapwood. The thujaplicins vary from 0% at the pith to as much as 1.8% in the outermost heartwood of an old-growth tree (Barton and MacDonald 1971; MacLean and Gardner 1956; Nault 1988). There is an overall decrease of fungitoxic extractives with increasing distance up the trunk (Barton and MacDonald 1971; Cartwright 1941; MacLean and Gardner 1956). As the tree matures, its ability to produce these extractives increases.

The lack of pitch or resinous extractives that are soluble in paint vehicles contributes to red cedar's good painting properties.

Nault (1988) showed that younger trees had higher amounts of extractives than the old-growth inner heart rings of the same age (i.e., years after seed germination). Thujaplicins and other extractives were absent or very low in some growth rings in some old-growth trees (Figure 6). This phenomenon has been attributed to the possible degradation of the thujaplicins into inactive compounds (Jin *et al.* 1988) which is discussed on page 10. The non-volatile fraction consists mainly of complex polyphenolic compounds. Of these, the main component is plicatic acid (Barton and MacDonald 1971; Swan *et al.* 1988) which is heat and light sensitive. Plicatic acid is responsible for bleedthrough in painted surfaces. Conversely, the polyphenols may be anti-oxidants which tend to stabilize paint films (Barton and MacDonald 1971).

Heartwood lignans and water-soluble extractives of the bark of western red cedar have been found to be moderately toxic to salmon, though less toxic than the foliage terpenes and thujaplicins (Peters *et al.* 1976). The direct release of red cedar leachates from landfills or logging debris into streams should be avoided.

The high extractives content of western red cedar is partially responsible for its good dimensional stability and paint-holding ability. The lack of pitch or resinous extractives that are soluble in paint vehicles contributes to cedar's good painting properties (Barton and MacDonald 1971).

Chemical Staining

Staining can be encountered on cedar surfaces exposed to the weather. When ordinary steel nails are used to secure cedar wood, a blue-black discolouration appears around the nail heads, triggered by the reaction between the water-soluble polyphenols in the wood and the iron in the nail. When the iron reacts with the thujaplicins in the cedar, as when steel comes in contact with light-coloured unseasoned cedar, a characteristic water-insoluble red stain is formed (Barton and MacDonald 1971).

Sometimes within months of installation, staining occurs as small specks of brown exudate or as patches of reddish-brown discolouration on finished exterior surfaces. The stains may be washed away easily with water on first appearance, but become insoluble under the action of sunlight and air (Barton and MacDonald 1971). The stains consist of water-soluble extractives of cedar which migrate to the surface in water solution, and deposit a brown stain as the water evaporates. The improper use of aqueous emulsion or latex paints applied directly to a cedar surface without modification, could cause this to happen. This can be prevented by priming the surface properly with an oil-based coat or by the addition of chemicals to the first coat of latex paint that would fix the coloured extractives and prevent them from migrating to the surface through subsequent coats of paint (Feist 1977). Water vapor from within the house condensing in the exterior walls during cold weather, or rain that penetrates thin porous paint coatings or joints in the siding, could also dissolve the extractives and bring them to the surface upon drying.

Resistance to Decay

Like almost all softwoods the sapwood contains very little extractives and, having very low natural durability, is regarded as perishable or non-durable. However western red cedar heartwood is renowned for its high decay-resistance. This natural durability is attributed to the presence of extractives, mainly the thujaplicins, and to a lesser extent, the water-soluble phenolics which are toxic to a number of wood-rotting fungi. Consequently, the pattern of decay-resistance within the heartwood parallels the distribution of these extractives in the stem (Barton and MacDonald 1971; Cartwright 1941; Englerth and Scheffer 1954; Erdtman and Gripenberg 1948; Roff and Atkinson 1954; Rudman 1962; van der Kamp 1986). Decay-resistance in coastal mature western red cedar is lower at the pith than in the outermost region of the heartwood, and lower at the top than at the butt of a log (Roff *et al.* 1963; Scheffer 1957).

Western red cedar heartwood is renowned for its high decay resistance.

Studies on western red cedar heartwood (Jin 1987; Jin *et al.* 1988; van der Kamp 1975) have shown that the decay process involves the successive action of microorganisms in the heartwood. The early invaders initially degrade the thujaplicins into non-toxic compounds, detoxifying the heartwood and preconditioning it for subsequent invasion by decay fungi. A product of this degradation process is thujin, named and described by Jin (1987) as having no toxicity to the common decay fungus of coastal western red cedar. In heartwoods where the inner zone has turned darker than the outer zone, the amount of thujaplicins was found to have decreased while that of thujin increased (Jin *et al.* 1988). Initial invasion by the fungi that can detoxify extractives occurs at the centre of the stem where decay onset takes place, and progresses outward (van der Kamp 1975). Thus, it is quite common to find trunks of overmature western red cedar trees that are hollow in the centre due to wood loss caused by decay.

In British Columbia, the total volume of accumulated decay in living trees is greater for western red cedar than for any other major conifer. Loss through decay and incidence of infection has been found appreciably higher in the Interior than on the Coast (Buckland 1946).

Since earlier research at the Western Forest Products Laboratory (now Forintek) indicated that the most effective extractives for imparting durability to western red cedar are β- and γ-thujaplicins (Barton and MacDonald 1971), it was assumed that the durability of red cedar heartwood could be determined by analysing for these two chemicals. Recently this has been shown to be a false assumption as the correlation between thujaplicin content and weight loss in laboratory decay tests is low (DeBell *et al.* 1999, DeBell *et al.* 1997). Clearly other compounds are contributing to the durability of the wood. Phenolic lignan compounds in western red cedar are weakly fungicidal (Roff and Atkinson 1954) but the degree to which they contribute to the natural durability is unknown. Other currently unknown fungicidal or fungitoxic components of western red cedar heartwood remain to be elucidated. The current belief is that the thujaplicins and lignans are part of an elaborate defense arsenal that has evolved to protect the heartwood from invasion by fungi and bacteria.

Thuja plicata is in the highest category for durability of any softwood listed in the European standard.

Results obtained in a soil block test by Freitag and Morrell (2001) showed that blocks cut from younger trees gave similar weight losses to those obtained with old-growth by Scheffer (1957). The authors inferred that the durability of younger second-growth wood had not changed from that of early older wood. Work on the durability of second-growth cedar is incomplete but the data previously discussed (Nault 1988) suggest that the extractive content is higher in vigorous young trees than in inner heartwood portions of old-growth trees of similar age since seed germination. This probably reflects the previously mentioned slow degradation of extractives by microorganisms in large old trees.

Durability Compared with Other Woods

Data comparing the decay resistance of western red cedar with other species are scarce. In ASTM D 2017 standard soil-block tests for natural durability, western red cedar was rated as durable as two Taiwanese woods: Formosan false cypress (*Chamaecyparis formosensis* Matsum.) and Taiwan incense-cedar (*Calocedrus formosana* (Florin) Florin). None of these three woods were significantly attacked by fungi (Lin *et al.* 1999). Taiwan red pine (*Pinus taiwanensis* Hayata) was significantly attacked by brown and white rot test fungi, while yellow cypress (*Chamaecyparis nootkatensis* (D. Don) Spach) was significantly attacked by a white rot fungus.

Although in North America western red cedar is widely considered to be a durable softwood there are no North American standards that classify natural durability. The European standard for natural decay resistance is EN 350-2 1994 *Guide to natural durability and treatability of selected wood species of importance in Europe.* A five-class system is used, with 1 being "Very Durable" and 5 being "Not Durable". The classification applies to the heartwood only, as the sapwood of all wood species is considered as belonging to Class 5. Additional subclasses can be added on: D meaning durable against wood boring insects; or S, meaning susceptible to the wood boring insects *Hylotrupes bajulus* (old house borer] and *Anobium punctatum* (common furniture beetle). Subclasses of D, M (moderately durable), or S are also used to describe resistance to termites.

An extract from the EN 350-2 standard is given in Table 6. North American western red cedar is Class 2 (durable against fungi) - S (*Hylotrupes*) - S (*Anobium*) - S (termites). This is in the highest category for durability of any softwood listed in the EN standard. European-grown red cedar is rated as Class 3

TABLE 6.
Natural durability and treatability of western red cedar in European standards

No.	Scientific Name	Common Name	Origin	Natural Durability				Treatability	
				Fungi	Hylotrupes	Anobium	Termites	Heartwood	Sapwood
2.6	*Larix decidua* Mill., *L. Kaempferi* (Lamb.) Sarg. [=*L.. leptolepis* (Sieb. & Zucc.) Gord.],. *L. x eurolepsis* A. Henr. *L. occidentails* Nutt.	Larch	Europe Japan	3-4	S	S	S	4	2
2.19	*Thuja plicata* D. Don	Western red cedar	N. America	2	S	S	S	3-4	3
			Cultivated in UK	3	S	S	S	3-4	3

Source: EN 350-2 Standard

(moderately durable) i.e., less durable than the same wood grown in North America. Larch is included in Table 6 as it is the most durable of the European softwoods and is Class 3 – 4 (slightly durable).

In Japan, western red cedar, along with yellow cypress, is included in Durability Class D1 that also includes the durable Japanese species hinoki (*Chamaecyparis obtusa* (Siebold & Zucc.) Endl.) and sugi (*Cryptomeria japonica* (Lf) D. Don).

Durability in Extreme Conditions

Despite western red cedar's natural durability, for applications with severe consequences of failure or with extreme decay hazard (e.g., utility poles, roofing material in high rainfall areas), it is advisable to pressure-treat the wood with preservatives to prolong service life.

Western red cedar utility poles are widely used in western Canada and the USA Pacific Northwest. These are almost always given a full-length pressure treatment with wood preservative in order to protect the sapwood. Red cedar shakes and shingles are also frequently treated with preservatives in western Canada. Unlike buildings in the early part of the 20th Century it is modern practice not to use battens under shakes and shingles but to nail directly to the roof sheathing. In wet areas this practice results in the cedar remaining wetter longer, which depletes the extractives from the continued soaking and the hazard for decay becomes high. Although western redcedar heartwood is highly impermeable, longitudinal preservative penetration can be achieved at the butts of shakes and shingles where extractive depletion is most rapid and decay is most likely to start because of exposure to the elements (Morris *et al.* 1995). The EN 350-2 standard (Table 6) covers treatability classes of different species based on general observations associated with vacuum/pressure treatment processes. Western red cedar heartwood is classified as 3 (difficult to treat) to 4 (extremely difficult to treat). This is similar to most other European- or North American-grown softwoods.

Roof shakes and shingles are exposed to strong ultraviolet (UV) light and wood is slowly eroded by ultraviolet light (sunlight) (Swan *et al.* 1988). Exposure studies showed an erosion rate of about 1 mm in 8 years on shakes with a southerly exposure at the University of British Columbia test site at Haney, BC (Byrne *et al.* 1987). Morris *et al.* (1995) have shown that copper- and chromium-based preservative treatments reduce surface erosion of shakes and shingles.

Resistance to Termites and Wood Borers

Western red cedar's natural resistance to termite attack has been found to vary with termite species, source of wood materials and feeding conditions. Western red cedar is "non-preferred" i.e., the termites will not eat western red cedar if they have access to other wood species with less resistance. However red cedar will be attacked if there are no other sources of food available (Carter and Smythe 1974; Mannesmann 1973; Su and Tamashiro 1986). Eating cedar will result in significant termite mortality.

The resistance to wood borers and termites of all of the softwood species listed in the EN standard (Table 6) is rated as Susceptible. However western red cedar clearly has resistance to termites. Lin and Chang (1999), in the reference mentioned under durability also tested the same woods in ASTM D 3345-74 no-choice tests against the Formosan subterranean termite, (*Coptotermes formosanus* Shiraki), one of the worlds most aggressive termites. Weight loss for western red cedar was similar to that for Formosan false cypress and Taiwan incense-cedar but western red cedar was not as termite-resistant as yellow cypress which gave the lowest weight loss of the four durable woods. Based on a large choice test of heartwoods of seven different species, western red cedar was given a “highly resistant” rating along with five other naturally-durable wood species including hinoki and yellow cypress (Suzuki and Hagio 1999). In this test the termites (*C. formosanus*) had other sources of food, such as non-resistant species and panel products that were preferentially consumed.

Western red cedar is “non-preferred” by termites....They will not eat the cedar if they have access to other foods.

In a laboratory study (Su and Tamashiro 1986) which examined the susceptibility of six wood species to attack by the Formosan subterranean termite (*C. formosanus*), western red cedar and redwood were the most resistant or least preferred by this termite compared to Douglas-fir, Ponderosa pine, Engelmann spruce and western hemlock. Approximately 50% of the termites that fed only on western red cedar died after three weeks. However, in the field where the resistance factors might have been broken down by microorganisms, and where the termites had access to other food sources and survived, both redwood and western red cedar were found to be severely damaged.

In another test, Mannesman (1973) exposed 21 different species of wood to *C. formosanus* and *Reticulitermes virginicus* (Banks). Under forced and choice feeding conditions, both species of termites preferred western red cedar to many of the other species.

Carter and Smythe (1974) exposed blocks of western red cedar heartwood to attack by *Reticulitermes flavipes* (Kollar) using forced and choice feeding conditions. The blocks were obtained from two different boards from a lumber yard. The authors obtained very different results for the two boards. Regardless of feeding conditions, one board was more susceptible than the other to attack by the termites. For one board, 60% of the termites survived after 8 weeks of feeding on western red cedar blocks. With the second board, practically no termites survived after only 4 weeks of feeding on blocks.

Health Effects

Western red cedar solid wood can safely be used in food contact. It has long been used for cooking vessels and food storage containers by First Nations in British Columbia. In more recent years baking fish on planks of cedar has become a popular gourmet food experience. Western red cedar extractives, while they are toxic to wood-destroying fungi and insects, are firmly encased in the wood. Although they are extractable, the wood has to be ground into a fine dust and then boiled with a solvent to obtain a solution of the extractives. Some of the volatile western red cedar extractives do evaporate from the surface of the wood used in a sauna, but they are not considered harmful to humans.

Contact dermatitis from red cedar is rare but where caused by exposure to the red cedar heartwood, it has been attributed to γ-thujaplicin and 7-hydroxyisopropyltropolone (Beaumink *et al.* 1973).

Allergy to western red cedar has been reported (Minore 1983). As with other woods most health problems from western red cedar appear to be associated with inhaling fine sawdust. Contact between the fine cedar dust and the mucous membranes is required for the allergic reaction to occur. Asthma or rhinitis (inflammation of the mucous membrane of the nose) sometimes develops after exposure to the dust (Mitchell and Chan-Yeung 1974). The physical presence of sawdust on the mucous membranes of the eyes and nose makes some individuals sneeze and tear (Chan-Yeung M. 1994). Symptoms such as nocturnal coughing and asthma can be delayed but persistent for days or weeks after exposure. Plicatic acid, the major non-volatile fraction in western red cedar extractives, has been identified as the responsible allergen (Mitchell and Chan-Yeung 1974). This was confirmed later by Frew *et al.* (1993) who found that in most patients with "western red cedar asthma", plicatic acid released histamine from bronchial mast cells.

Only 2 to 5% of people develop an allergic sensitivity to one or more compounds found in wood, usually through inhalation of dust (Woods and Calnan 1994). Incidence of health problems caused by wood and its by-products (such as sawdust) is low compared with many other industrial materials (Bolza 1980). Nonetheless because fine wood dust has been identified as a human irritant/sensitizer/carcinogen, precautions should be taken to prevent exposure, particularly to the eyes and respiratory system. Good industrial hygiene requires that engineering controls be used where feasible to reduce workplace levels below exposure limits. The workplace around sawdust of any type should therefore be well ventilated, with the sawdust removed by exhausting from the machines producing the dust. Respirators may be used under certain conditions (OSHA, undated).

A water extract of western red cedar heartwood has been found to have an inhibiting effect on the growth of a wide variety of bacteria and fungi even after prolonged boiling (Southam 1946). Large doses of the extract caused no ill effects on mice.

Mechanical Properties

Data from strength tests of small clear specimens were the traditional basis for deriving allowable design properties for lumber, and are still used for establishing allowable working stresses (not covered by in-grade testing methods) such as compression perpendicular-to-grain and shear parallel-to-grain. The average strength properties of western red cedar as determined by standard strength tests of small clear specimens in green condition (Jessome 1977) are presented in Table 7. These strength properties apply only to western red cedar grown in Canada. Values adjusted to air-dry condition (12% MC) are also given. Information and principles for converting standard clear-wood strength values to working stresses in design are given in the American Society for Testing and Materials, Annual Book of Standards, Section 4, D-2555 (1996).

In the mid-1970s, Professor Borg Madsen of the University of British Columbia suggested that design properties for sawn lumber be based on tests of full-size wood (Barrett and Lau 1994). This led to the concept of in-grade testing which would produce data that closely reflect the behaviour of products in end-use conditions. No in-grade testing has been done on western red cedar because it is a specialty wood and is not used much for studs or structural light-framing. Nonetheless, western red cedar has been grouped with "lesser volume species" under the commercial name "Northern" species for purposes of assigning specified strengths to the various grades of western red cedar graded under the rules of the National Lumber Grades Authority (NLGA). The "Northern" species group includes all species not included under any of the three major species combinations (S-P-F, Hem-Fir, D-fir-L) graded under the NLGA rules (Canadian Wood Council 2001). The strengths and modulus of elasticity for western red cedar posts and timbers are also given in the Wood Design Manual (Canadian Wood Council 2001).

TABLE 7.
Mechanical properties of western red cedar based on clear-wood samples* (after Jessome 1977)

	Moisture Condition		Number of Samples	Green		Air Dry
	Relative Density			0.312[a]		0.339[b]
Static Bending	Stress at Proportional Limit (MPa)		204	21.4	(19.9)	34.4
	Modulus of Rupture (MPa)		204	36.5	(13.2)	53.8
	Modulus of Elasticity (MPa)		204	7240	(12.7)	8270
Impact Bending	Drop of 22.7 kg Hammer at Complete Failure (mm)		100	410	(23.0)	430
Compression Parallel-to-Grain	Stress at Proportional Limit (MPa)		108	15.9	(17.6)	27.4
	Maximum Crushing Stress (MPa)		406	19.2	(15.1)	33.9
	Modulus of Elasticity (MPa)		108	8070	(13.4)	9100
Compression Perpendicular-to-Grain	Stress at Proportional Limit (MPa)		114	1.92	(28.4)	3.43
Hardness	Load Required to Imbed 11.3 mm Sphere to Half Diameter (N)	Side	222	1180	(20.1)	1470
		End	111	1920	(16.0)	3000
Shear Parallel-to-Grain	Maximum Stress (MPa)		72	4.80	(13.8)	5.58
Tension Perpendicular-to-Grain	Maximum Stress (MPa)		72	1.64	(26.9)	1.46

Numbers in parenthesis are the coefficients of variation derived from tests of green small clears but found also to apply to air dried cedar.
a Basic Relative Density (oven-dry weight/green volume)
b Nominal Relative Density (oven-dry weight/air-dry volume)

END USES

Overview

The unique properties of western red cedar enable end uses distinct from other species of softwoods. Western red cedar is renowned for its naturally-occurring resistance to moisture, decay and insect damage. Its natural durability makes western red cedar ideal for exterior uses: roofs, siding, soffits, porches, fences, sashes, decks, windows and doorframes. Western red cedar is the preferred material for outdoor applications that seek a natural look combined with stability and durability, from siding and patio decking to fences, planters, screens, shelters and garden furniture. With its richness of grain, texture and color, cedar complements any architectural style, from traditional to contemporary.

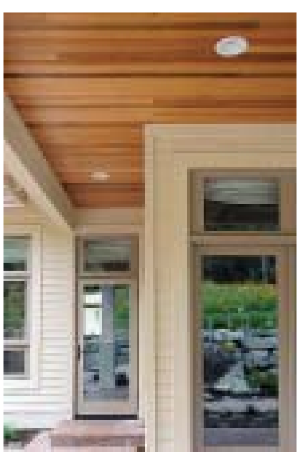
Indoors, cedar's dimensional stability and its appearance makes it perfectly suited to a variety of uses including window blinds, paneling, moldings and sauna paneling. The wood's cellular structure incorporates interior air spaces that give it an insulation value higher than most woods and much higher than brick or concrete. Buildings featuring cedar panelled, ceilings, or siding will therefore tend to stay cooler in the summer and warmer in the winter. Western red cedar also has excellent sound suppression and absorption qualities and is therefore used in concert hall interiors for acoustic enhancement.

Cedar is simple to work using either hand or machine tools. It is lightweight and easy to handle and install for both the professional and do-it-yourselfer. The wood shapes, planes, sands, nails and glues well. It is free of pitch and resin and makes an excellent base for a wide range of finishes. It finishes to a richly glowing surface that can be enhanced with transparent and full-bodied stains or with paints.

Siding and Panelling

Appearance, durability, insulation value and dimensional stability are western red cedar's primary advantages as exterior siding and interior paneling material Its ability to damp vibrations and reduce or confine noise makes it particularly effective for use as paneling. It is suitable for any variety of architecture and is versatile enough to be used in residential, commercial or industrial structures. It is widely used in saunas because of its low thermal conductivity.

Western red cedar siding is available in a range of types and grades. Bevel siding is the most widely used cedar siding type. It is produced by resawing boards at an angle to produce two pieces thicker on one edge than the other. The manufacturing process results in pieces with one face saw-textured. The other face is smooth or saw-textured depending on the grade and customer preference. Bevel siding is installed horizontally and gives an attractive shadow line that varies with the thickness of siding selected.



Bevel siding is available in clear and knotty grades. Clear siding gives premium quality appearance. Knotty siding has warmth and casual charm ideal for homes, cottages, club-houses and applications where a rustic appearance is desired. In addition to solid bevel siding, some companies produce finger-jointed bevel siding. The precision-fitted joints are virtually invisible and stronger than the surrounding fiber.

Tongue-and-groove exterior siding or interior panelling is widely used for its character appearance and versatility. It can be installed horizontally, vertically and diagonally, each giving a distinctly different look. The joints between adjoining pieces are usually v-shaped but flush, "reveal" and radius joints are also available. The different joints and surface textures in tongue-and-groove siding combine to provide a range of line effects that enhance the product's versatility.

Lap sidings are normally supplied in a variety of patterns. Channel siding is a popular type of lap siding and is used when a rustic appearance is desired. It is a versatile siding that can be installed vertically, horizontally or diagonally. In channel siding the profile of each board overlaps that of the board next to it creating a channel that gives shadow line effects, provides excellent weather protection and allows for dimensional movement.

Board and batten designs use wide clear or knotty boards spaced apart with narrower battens covering the joints. Various combinations of different widths are used to create different looks suitable for large or small scale applications.

Instructions for installing different types of cedar siding on different wall constructions, the choice of different types and patterns and their applications are well described in WRCLA publications titled "Specifying Cedar Siding" and "Installing Cedar Siding" (www.cedar-siding.org).

Trim Boards

Western red cedar is widely used for exterior trim such as corner boards, fascia, skirting, and door and window trim. Western red cedar trim complements all contemporary cladding materials and a wide range of architectural styles.

Western red cedar trim boards are available in clear and knotty grades. Clear grades are the highest quality straight-grained products and are specified when appearance of consistent even quality is desired. Knotty boards present a more rustic appearance.

The WRCLA's "Specifying Trim Boards" provides more specific information on available sizes and grades.

Decking and Accessories

Decks are a popular way to extend living space to the outdoors, integrating home and landscape and giving a contemporary look to a traditionally-styled home. The choice of decking material is just as important as good design and quality construction. Western red cedar is prized for decking because of the wood's pleasing appearance, natural durability and dimensional stability. Other woods require chemicals to protect them from decay and insect attack but western red cedar is one of the few woods with its own "grown-in-the wood" preservative. It shrinks and swells much less than other softwood species, stays flat and straight, and resists checking. It is free of pitch and resins making it an excellent base for protective coatings.

Western red cedar is a renewable material, harvested from sustainably-managed forests. Plastic composite decking materials require much larger amounts of energy to produce. A deck constructed with western red cedar is enjoyable even at the warmest time of the year. While decks made of plastic or composites can become unbearable in the summer heat, western red cedar's low density ensures a cool comfortable surface. Western red cedar decks are firm but resilient underfoot, not hard and unyielding as many other materials.

To make selecting the right western red cedar decking easier, the Western Red Cedar Lumber Association has established four industry recognized grade categories:

WRCLA Architect Clear – The finest, knot- free quality. Its fine-grained heartwood appearance will meet the needs of the most demanding clients requiring a refined and even look.

WRCLA Custom Clear – Clear appearance with added grain and small knot character which give it a more natural "woody" appearance for custom designs.

WRCLA Architect Knotty – Decking with a slightly rustic "woody" character including sound and tight knots, a choice where the natural beauty and charm of a knotty deck are desired.

WRCLA Custom Knotty – A rustic economical deck. Nonetheless this product is made with high manufacturing standards; knot size and quality are tightly selected.

In addition to these decking grades, western red cedar is produced in a range of patterns and sizes that offer flexibility in design. Decks can be accessorized with a variety of pre-cut handrails, balusters, post caps, fencing, lattice and other decorative items.

More information on western red cedar decking can be found in "Specifying Cedar Decking" a publication by the Western Red Cedar Lumber Association (www.cedar-deck.org).

Fences and Gates

Properly constructed and maintained, a cedar fence will look good for years. Also, gates made with western red cedar make a great first impression. Using materials of the same quality and texture used on the home ensures continuity and a harmonious balance.

Design ideas, sizes and grade descriptions are available in the WRCLA's "Western Red Cedar Fences and Gates" publication or on the web at (www.cedar-outdoor.org).

Timber Construction and Landscape Structures

Solid sawn timbers allow diversified construction features to be made. They can be used for many types of engineered structures, commercial, industrial and residential buildings as well as landscape structures such as bridges, arbors, pergolas, gazebos, field houses and others. For both of these use groups, western red cedar offers the advantages of beauty, design flexibility, exceptional dimensional stability and natural durability.

Specific information on mechanical and physical properties and grades is available in the WRCLA's "Designer's Handbook" and "Specifying Western Red Cedar for Timber Construction and Landscape Structures" publications.

Log Homes

A major use of western red cedar is in log houses—either as solid wood or as a component of laminated logs. Solid logs are peeled and machined to produce pieces that may be cylindrical or square in cross-section, or combinations of both. In laminated house logs, cedar is used as an exterior component for its visual quality. Western red cedar boards are also used to incorporate an insulating foam interior to achieve a significantly higher coefficient of thermal resistivity than is commonly obtained with solid wood (Gorman *et al.* 1996).

Shakes and Shingles

Western red cedar has been considered superior to other species in the manufacture of shakes and shingles because of its light weight, dimensional stability, straight grain, and natural durability. Western red cedar shakes and shingles are used for roof or exterior wall covering. The basic types and grades of shakes and shingles manufactured for these uses are described in the Canadian Standards Association Standard 0118.1-97 (1997). For the top grade, 100% clear heartwood and edge-grain are required.

Shakes are usually about 60 cm (24") long, usually with one split face (which gives the roof a rough textured look) and a sawn back, and are thicker at the butt than shingles. Shingles are usually about 40 to 46 cm (16 to 18") long, and have two sawn faces. Under many conditions, western red cedar shingles and shakes can provide good service life in their natural state. However, in moist warm climates, high rainfall areas or under conditions of high decay potential, such as in the shade and drip of trees, where the fungitoxic extractives can be depleted through water leaching, a reduced lifespan of 10 years for untreated western red cedar roofs has been reported. Under these

conditions, pressure treatment with wood preservative is highly recommended for longer service life. Shakes and shingles are available to the consumer with or without chemical preservative treatment, and with or without fire retardant treatment. The Canadian Standards Association (1997) recommends that fastenings and flashings used with treated shakes and shingles be made of metals that are resistant to the chemical action of the preservatives or fire retardants that are used. Stainless steel type 304 or 316, or hot-dipped galvanized steel nails are the recommended fasteners.

Poles

As a utility pole, western red cedar has the advantage of large size, light shipping weight, and easy climbing-spur penetration. Western red cedar poles are used extensively to carry distribution and transmission utilities in western Canada and the Pacific Northwest. Approximately 4500 western red cedar poles removed from service in western Canada are recycled annually in a Vancouver custom-cut sawmill. Despite years of service these poles have a considerable amount of sound heartwood wood that is cut into decking, landscaping timbers and fencing.

Pulp

Western red cedar residues from sawmills are commonly chipped and sent to pulp mills in coastal BC where they constitute about 15% of the total chips used. About 90% of the cedar chips are supplied from sawmill residues and about 10% come from low-grade logs that cannot be made into solid wood products. The species is an important constituent of specialty pulps for fine papers. Western red cedar pulp is produced by the kraft process and is particularly suitable for the manufacture of light-weight coated papers, printing, writing, tissue and computer papers. Pure or mixed pulps are used in the manufacture of specialty products such as surgical drapes, masks and gowns which require tailor made properties.

Cedar's excellent fiber properties for papermaking include thin cell walls, good collapsibility and flexibility, which promote interfiber bonding within the sheet and produce a strong product with low porosity, good opacity and exceptional smoothness. Compared with the bleached kraft pulps from western hemlock, Douglas-fir, and southern pine, western red cedar ranked first in burst, fold and tensile properties but had lower tear (Murray and Thomas 1961).

While regarded as producing a superior softwood pulp, the use of western red cedar as a pulpwood material is not without its technical challenges to pulp mills. Relatively low wood density gives lower kraft pulp yields than other species—as low as 60% of Douglas-fir or 70% of hemlock (Hatton 1988). It is not preferred for groundwood pulp because the pulp has to be bleached to a brightness acceptable for newsprint manufacture. Sulfite pulp also is low in brightness and bleaches with difficulty.

It requires longer pulping time and more chemicals than western hemlock. Pulping by the sulphite-anthraquinone process gives low yield but produces pulp bleachable to a satisfactory final brightness (MacLeod 1987). The corrosive nature of western red cedar extractives makes it necessary to line digesters with corrosion-resistant stainless steel. The stringy bark of western red cedar is difficult to remove and causes operating problems.

Speciality Products

A number of specialty products are made from western red cedar. These include doors, windows, blinds, musical instruments, boxes, moldings, garden furniture and bird houses. Special stocks are also available to wood carvers, woodworkers and other artisans who require wood with the unique properties of western red cedar. In terms of musical instruments, western red cedar is used for soundboards for guitars and harpsichords in BC and Europe. The wood properties of western red cedar that make it suitable for this use are its fine texture and straight-grain, good resonance and high strength-to-weight ratio. According to guitar makers in BC wood from older trees with finer texture and higher density and stiffness is preferred.

A unique appearance product is western red cedar-faced plywood. This decorative plywood is available from speciality suppliers. Other panel products such as particle board and fibreboard have been made in the past from western red cedar mill residues including bark, sawdust and solid wood trimmings but these are no longer used commercially.

Oil from the leaves and branches has been produced by steam distillation in British Columbia and sold since 1987. The leaf oil has an aromatic fragrance and is used as a base in manufacturing perfumes and toiletries. Oil from western red cedar heartwood residue is also produced on a small scale by steam distillation. Potential uses have been proposed for extractives of western red cedar (Barton and MacDonald 1971) and markets are currently being developed for purified extractives.

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