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THE ECOLOGY AND CULTURAL SIGNIFICANCE OF WESTERN LARCH:

A LITERATURE REVIEW

By

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The ecology and cultural significance of western larch: a literature review

Chair: Fletcher Brown F. B.

Western larch (*Larix occidentalis*) is an ecologically and culturally important tree throughout its range in the Columbia River Basin of North America. Schmidt and others (1976) summarized available literature on the species in the U.S.D.A. Forest Service Technical Bulletin 1520, *Ecology and Silviculture of Western Larch Forests*. Since then, substantial additional research on western larch and its forests has been completed. This literature review is a partial review of the western larch literature to date to be incorporated into a revision of Schmidt and others' 1976 publication.

Topics of emphasis include phenology and genetics; disease, insect, and animal damage; vegetation types and distribution; succession; fire ecology; growth and yield; and uses of western larch. In addition, management practices relevant to the above topics are discussed along with an overview of western larch biology and ecology.

Finally, the history and purpose of the project are summarized, and a detailed description of the literature review and writing process used, practical suggestions for similar projects, and personal reflections from the author are included.

Author's note

This report is intended for inclusion in a revision of USDA Forest Service Technical Bulletin 1520, *The Ecology and Silviculture of Western Larch Forests*, by Schmidt and others (1976) (See Chapter Five for a more detailed project background and description). As such, readers may notice that selected passages were used verbatim from the original 1976 publication, with permission to do so.

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CHAPTER ONE

ECOLOGY OF WESTERN LARCH

A. BOTANICAL CHARACTERISTICS

Western larch is a fast growing, deciduous conifer native to forests of the northwestern United States and adjacent Canada (Arno 1976; Fiedler and Lloyd 1995; Schmidt and Shearer 1990; USDA NRCS 2002). The species is the largest larch in North America and is among the world's largest larch species. It typically grows 100 to 180 feet (30-55 m) tall (American Forestry Association 1973; Flora of North America Association 2000; Gower and Richards 1990; Hitchcock and others 1969; Hosie 1969; Schmidt and Shearer 1990; Welsh and others 1987), with diameters of three to four feet in 250 to 400 years (Flora of North America Association 2000; Hadfield and Magelssen 2000; Hosie 1969;

Welsh and others 1987). Basal area increases rapidly to about age 40, then decelerates and nearly levels off after age 100 (Schmidt and Shearer 1990).

At 600 to 700 years of age, the trees may reach a height of more than 200 feet (61 m) and a d.b.h. of five to eight feet (1.5-2.4 m). A tree measuring more than 24 feet (7.3 m) in circumference (about 92 inches d.b.h. and 177 feet tall) was reported near the Kootenai National Forest in Montana (American Forestry Association 1973). Koch (1945) reported a stump at Seeley Lake, Montana, with 915 growth rings; the diameter measured 78 inches (198 cm) inside bark. Another tree in the same stand measured 88 inches (224 cm) d.b.h. when cut. Other large specimens include one tree found in the Wenatchee National Forest, Washington, in 1993 that was 189 feet (57.6 m) tall, 230 inches (584 cm) in circumference, with a 35 foot (10.7 m) spread, and one on the Lolo National Forest, Montana, with a circumference of 264 inches (670cm), height of 153 feet (46.6 m), and spread of 34 feet (10.4 m) (Gangloff and Cowan 2000).

A deep, spreading root system stabilizes these large trees (Gower and Richards 1990; Hosie 1969; Larsen 1916). In a synthesis of literature on northwestern trees, Minore (1979) ranked western larch root depth in the middle of five categories. Bark in mature western larch trees is thick and furrowed into large, flaky plates (Flora of North America Association 2000; Hitchcock and others 1969; Schmidt and Shearer 1990; Welsh and others 1987). At age 50, basal bark thickness ranges from five to 10 inches (12-25 cm), and at age 100 bark is 10 to 18 inches (25-45 cm) thick (Arno and Hammerly 1977). Western larch trunks are usually bare for one-half to one-third of the height when in stands, while trees in the open may have branches to within a few feet of the ground (Hitchcock and others 1969; Hosie 1969; Welsh and others 1987). Crowns are generally short, open, and pyramidal with nearly horizontal branches, though branches may droop in the lower crown of older trees grown in the open (Flora of North America Association 2000; Gower and Richards 1990; Hitchcock and others 1969; Hosie 1969). Crown length, width, and density were all ranked low in Minore's (1979) synthesis of literature on northwestern trees.

Branches are stout and brittle and buds are small, rounded, and hairless (Hitchcock and others 1969; Hosie 1969; Welsh and others 1987). As trees mature, clustered epicormic branches replace older branches, beginning with the lower portion of the crown. Eventually, epicormics, which grow from dormant buds at the base of first order branches, comprise the entire crown (Lanner 1995). Clusters of 15 to 30 slender, soft, spirally-arranged needles one to two inches (2.5-5.0 cm) long arise from dwarf twigs (Hitchcock and others 1969; Hosie 1969;

Welsh and others 1987). Western larch foliage is replaced annually (Gower and others 1989; Gower and Richards 1990).

Male western larch cones are 0.4 inch (1mm) long (Hitchcock and others 1969; Welsh and others 1987). Ovulate cones are papery, one to 1.5 inches (1 cm) long and 0.5 to 0.6 inch wide with long subtending bracts (Arno and Hammerly 1977; Flora of North America Association 2000; Hitchcock and others 1969; Hosie 1969; Welsh and others 1987). Seeds are 0.1 inch long with 0.2 inch wings (Flora of North America Association 2000; Hitchcock and others 1969; Hosie 1969; Welsh and others 1987).

B. SITE CHARACTERISTICS

1. Physiography

Western larch is the most shade-intolerant tree in the Northern Rocky Mountains (Baker 1949). Only in its early seedling stage will it tolerate partial shade (Haig and others 1941). Because it needs well-lighted areas for maximum development, it performs best in open stands (Hosie 1969).

Western larch occupies valley bottoms, benches, and mountain slopes. It is found on all exposures but is more common on north and east aspects (Flora of

North America Association 2000; Hitchcock and others 1969; Schmidt and Shearer 1990, 1995). South and west exposures are often too severe for seedling establishment (Schmidt and Shearer 1990, 1995). This trend is more pronounced in the southern parts of its range, where it is found almost exclusively on north- and east-facing slopes (Fiedler 1995; Fiedler and Lloyd 1995).

Western larch is usually found at elevations of 1,500 to 5,500 feet (460-1,700 m) in the northern portions of its range and may be found at elevations over 7,000 feet (2,100 m) in the southern parts of its distribution (Flora of North America Association 2000; Hosie 1969; Schmidt and others 1976). Rehfeldt (1995b) found that latitude and elevation affected genetic variation patterns of western larch populations in the Rocky Mountains. Populations from more northern areas and from high elevations had lower growth potential, lower resistance to disease, and lower survival. Elevational ranges for some states and one province in western larch's range are shown in Table 1.

Table 1: Western larch elevation range by state and province

Montana	3,000-7,200 feet (900-2,200 m) (Knudsen and others 1968)
Oregon	3,500-6,500 feet (1,000-2,000 m) (Knudsen and others 1968)
Washington	2,000-5,500 feet (600-1,700 m) (Arno and Hammerly 1977; Knudsen and others 1968)
British Columbia	2,000-5,550 feet (600-1,700 m) (Arno and Hammerly 1977)

2. Soils

Western larch is found on a wide variety of soil types, most of which are derived from bedrock or glacial till, but some are of loessial or volcanic ash origin. Deep, porous soils, such as those of mountain slopes and valleys are ideal, and growth is related to soil depth (Fiedler 1995; Hosie 1969; Schmidt and Shearer 1990, 1995; Schmidt and others 1976). Western larch is also quite dependent on mineral soil or burned seedbeds, more so than any associated tree species including lodgepole pine (Fiedler 1995; Schmidt and Shearer 1990). The species is adapted to medium and coarse textured soils with a pH of six to seven, and has no salinity tolerance (USDA NRCS 2002).

3. Climate

Western larch occupies relatively cool, moist climatic zones. Its upper elevational range is limited by low temperatures, while the lower extreme is limited by low precipitation (Fiedler and Lloyd 1995; Fiedler 1995; Schmidt and Shearer 1990; Schmidt and others 1976). Average climatic conditions for western larch's range and for four habitat types in which western larch occurs are listed in Tables 2 and 3, respectively.

Table 2: Climate conditions in western larch's range (Schmidt and Shearer 1990)

Temperature	45° F (7° C)
Maximum temperature	84° F (29° C)
Minimum temperature	15° F (-9° C)
Growing season temperature	60° F (16° C)
Frost free days	60-160 days
Annual precipitation	28 in (710 mm)
Growing season precipitation	6 in (160 mm)
Snowfall	103 inches (2620 mm)

Table 3: Climatic conditions in four western larch forest habitat types (Fiedler and Lloyd 1995)

	Douglas-fir	grand fir	western redcedar-western hemlock	Engelmann spruce-subalpine fir
Mean annual precipitation (mm)	370-570	500-680	570-1,130	700-850
Mean growing season precipitation (mm)	180-270	200-290	210-370	200-320
Mean annual snowfall (cm)	120-350	193-450	130-560	200-620
Mean annual temperature (°C)	4.0-7.5	2.5-4.0	2.5-7.8	1.0-2.5
Frost-free conditions (days/year)	40-140	35-80	50-170	40-70

C. REGENERATION PROCESSES

1. Pollination and Seed Production

Western larch is monoecious with both staminate and ovulate cones distributed throughout the crown (Schmidt and Shearer 1990, 1995). Its pollen is distributed by wind and is less abundant than that of other conifers. Owens (Owens 1995) described the physiological details of pollination in western larch.

Western larch cone production may begin as early as age eight though it is unusual on trees less than 25 years old. Heavier crops typically begin at approximately 40 to 50 years of age and continue for 300 to 500 years (Schmidt and Shearer 1995; Shearer 1989b). Trees produce cones annually, but crop size varies with year and location; heavy cone crops occur every five years on average, with fair to poor crops in other years (Schmidt and Shearer 1990; Shearer and Carlson 1993). Shearer and Carlson (1993) reported an annual average of 1,393 potential cones per tree over a six-year period. Because western larch cones are borne throughout the crown, the size of the crop generally corresponds to the size of the crown (Schmidt and others 1976; Schmidt and Shearer 1990, 1995). Shearer and Kempf's (1999) literature review reported that the number of cones also tends to increase with increased spacing of trees.

On average each mature cone produces 39 seeds, but some may contain as many as 80, and mature stands of western larch may produce more than 0.5 million seeds per acre (1.2 million seeds/hectare) (Schmidt and Shearer 1990). Roe (1966) described a method for estimating the size of western larch seed crops up to one year in advance.

2. Seed Dispersal

Western larch seeds are relatively small and light, 137,000 to 143,000 per pound (301,000-315,000/kg) (Arno and Hammerly 1977; Schmidt and Shearer 1990; USDA NRCS 2002). They are easily dispersed by wind and are well adapted for establishing on mineral soil following extensive stand-destroying wildfire (Shearer and Stickney 1991). Most western larch seeds are distributed within 328 feet (100 m) of the parent. However, depending on wind conditions, they may be dispersed up to 820 feet (250 m) or more (Schmidt and Shearer 1995). This distance is comparable to that of Engelmann spruce seeds, but is longer than Douglas-fir and subalpine fir (Schmidt and Shearer 1990). Seed spread rate is considered moderate (USDA NRCS 2002).

3. Germination

Under natural conditions, western larch seeds are viable only until the year following fertilization (Schmidt and others 1976). Viability typically increases with crop size and decreases with parent tree age (Schmidt and Shearer 1990). Inviable seed results from lack of pollination, inviable pollen, lack of fertilization, later ovule abortion, or embryo abortion (Owens and Molder 1979c). Over a six-year period, Shearer and Carlson (1993) found that four percent of potential seeds at the time of bud burst matured as filled seeds.

Seeds of western larch germinate well on a variety of seedbeds and aspects (Schmidt and others 1976), but Stoehr (2000) found that germination and survival was greatest in mineral soil. In a synthesis of literature on northwestern trees, Minore (1979) ranked western larch germination and survival in the highest category for mineral seedbeds, in the middle category for burned seedbeds, and in the lowest category for organic seedbeds.

Germination occurs at or above the soil surface. Natural stratification during winter results in rapid, complete germination. Spring-sown western larch seeds without stratification germinate slowly and erratically; some do not germinate until the following season (Schmidt and Shearer 1990).

The ideal temperature for germination is 80° Fahrenheit (27° C), but germination can occur at temperatures as low as 65° Fahrenheit (18° C). Oswald and Nuenschwander (1994) reported seed predation and shade both had negative effects on germination rates of western larch, though shading was not a significant factor. Shade appears to be more important as seedlings develop.

On average one western larch seedling will establish for every 53 seeds produced and dispersed (Shearer 1981). Seedlings grow rapidly and vigorously

(Schmidt and Shearer 1990,USDA NRCS 2002), averaging two inches (5 cm) of growth during the first season and 12 inches (30 cm) per year over the next four years. Western larch seedlings grow faster than any other Rocky Mountain conifer until 100 years of age except lodgpole pine, which begins to grow at a similar rate at age 50 (Arno and Hammerly 1977; Schmidt and Shearer 1990).

4. Survival

Seedling mortality is usually highest in the first season; losses after year three are minimal (Schmidt and Shearer 1990). Biotic factors, such as fungi, birds, and rodents, cause the most first year seedling deaths early in the season, but drought is more detrimental after mid-July (Schmidt and Shearer 1990; Schmidt and others 1976). Newly germinated seedlings were killed by high soil-surface temperatures (> 130° Fahrenheit (54° C)) in Montana, and these effects were most common on western and southern exposures (Schmidt and others 1976; Shearer 1967).

5. Site Variation

Site requirements for establishment and growth of western larch seedlings are more specific than those for germination. Seedlings are well adapted to the mineral soil and sunlight of exposed seedbeds, such as those created by burning or mechanical scarification. They do not thrive in areas with undisturbed litter, humus, sod, or heavy root competition (Arno and Hammerly 1977; Geier-Hayes 1987; Schmidt and others 1976; Schmidt and Shearer 1990, 1995; Shearer 1975).

For the first few years, partially shaded seedlings usually grow faster than those in full sunlight; thereafter, seedlings in full sunlight outgrow shaded seedlings. North, northwest, and northeast exposures and gentle to flat topography are best for seedling survival; high surface temperatures on south and west exposures may cause seedling mortality (Schmidt and others 1976; Schmidt and Shearer 1990; Shearer 1967).

D. PHENOLOGY

Western larch's active growth occurs from May through August (Schmidt and Shearer 1990; USDA NRCS 2002). Tables 4, 5, and 6 summarize the available phenological information on western larch.

Table 4: Western larch vegetative phenology

Stage of Development	**Timing**
Buds begin to appear	early fall (Schmidt and Shearer 1990)
Buds swell, then open	late March and April (Shearer and Carlson 1993)
Needle growth declines	mid-May (Shearer and Kempf 1999)
Diameter growth begins	mid-May (Shearer and Kempf 1999)
Diameter growth peaks, needle growth ends, height growth begins	mid- to late June (Shearer and Kempf 1999)
Height growth peaks	mid-July (Shearer and Kempf 1999)
Height growth complete	mid-August (Shearer and Kempf 1999)

Table 5: Western larch phenological observations in the Northern Rockies from 1928-1937 (Schmidt and Lotan 1980).

Stage of Development	**Average date**	**Range**
Bark slips	4/26	3/12-6/3
Shoots start	5/14	4/10-7/2
Buds burst	4/30	3/20-6/11
Pollen starts	5/20	4/26-6/29
Pollen ends	6/3	5/10-7/14
Shoots end	8/1	6/18-9/6
Bark sticks	8/25	7/15-10/2
Winter buds formed	8/22	7/11-10/11
Cones full size	8/6	7/2-9/11
Cones open	9/4	7/31-9/30

Table 6: Summary of western larch reproductive development

Stage of Development	**Timing**	**Notes**
Cone initiation	early summer (Owens 1995; Schmidt and Shearer 1990)	
Buds appear	early fall (Schmidt and Shearer 1990)	
Pollen and seed cone buds develop	prior to winter dormancy (Owens 1995; Schmidt and Shearer 1990)	
Pollen and seed cone development begins	late March and April (Shearer and Carlson 1993)	
Pollen and seed conelets appear	mid-April to mid-May	
Pollination	late April to early June (Schmidt and Shearer 1990)	
Fertilization	June to July (Owens and Molder 1979c; Schmidt and Shearer 1990)	Fertilization occurs 6-8 weeks after pollination.
Cones mature	mid- to late August	Cones mature faster during warmer summers.
Cone opening begins	late August and early September (Schmidt and others 1976; Schmidt and Shearer 1990)	Long periods of cool or moist weather may delay opening (Schmidt and Shearer 1990).
80% of seeds dispersed	mid-October (Schmidt and others 1976; Schmidt and Shearer 1990; Shearer and Carlson 1993; Shearer 1977)	Seeds dispersed later usually have lower viability (Shearer 1977).
Cones fall	winter	Some cones may remain on trees through the next summer (Schmidt and Shearer 1990).
Germination	late April through early June (Schmidt and Shearer 1990)	Germination roughly coincides with snowmelt and occurs 1-2 weeks before that of associates. Germination occurs earlier on lower elevation or exposed sites and later at upper elevations or in sheltered areas (Schmidt and others 1976).

E. GENETICS

Little DNA sequence information is available for the genus *Larix* (Khasa and others 2000b). However, genetic linkage maps have been constructed for European larch and Japanese larch (Arcade and others 2000), and repetitive DNA studies have been completed with Japanese larch (Hizune and others 2002). Studies indicate that there is considerable genetic differentiation within and among larch species (Pâques 2001). Semerikov and Lascoux (1999) found that western larch and alpine larch form a genetically distinct group compared to other European and North American larch species. Their data indicate that larch species may have migrated from Eurasia to North America. Boyle and others (1989) summarize 65 years of larch experiments by the Tree Genetics and Breeding Project of Forestry Canada's Petawawa National Forestry Institute.

Genetics apparently determine water use efficiency and stem unit production, characteristics which, along with predetermined height growth, showed positive correlations with mean height of western larch (Zhang and others 1995). Both predetermined and free-growth of western larch annual shoots are influenced by genetics as well as environmental changes from year to year. The genetics appeared to vary within, and to a lesser degree, among populations (Joyce 1985, 1987). Chandler's (1967) data also indicated that genetics was responsible for the considerable differences in growth of trees, hybrids, and cuttings.

1. Variation

Western larch varies genetically between and among natural populations as well as with altitude and geography. These differences can account for growth and development, morphological, and pest resistance traits (Rehfeldt 1995a). The degree of western larch genetic variation, when compared to other Northern Rocky Mountain species, suggests that the species is an intermediate between specialists, such as Douglas-fir and lodgepole pine, and generalists, such as western white pine (Rehfeldt 1984).

Genetic variation of western larch populations in the Inland Empire was within the range of variation reported for other western conifers, though western larch variation was lower than most species, indicating that genetic drift has been an influential factor in the the genetic composition of western larch populations (Fins and Seeb 1986). Stand density may influence the rate of outcrossing in western larch populations. However, barriers that limit pollen distribution may also be factors (El-Kassaby and Jaquish 1996). Populations in British Columbia tended to have greater levels of variation than those in the United States. A significant portion of the variation occurred within populations, and genetic and geographic distances were significantly ($p < 0.01$) correlated. In addition, two genetically unique populations were found and recommended for protection (Jaquish and El-Kassaby 1998).

Rehfeldt (1982) found that phenology, growth potential, and cold hardiness of buds varied in 82 populations of western larch. Some variation was related to elevation: as elevation increased, bud burst occurred later, bud set occurred earlier, and growth potential decreased. For unknown reasons, bud hardiness was not related to seed source elevation (Rehfeldt 1982).

Rehfeldt's (1992) study of natural western larch populations' genetic structure found that western Montana populations have the "lowest growth potential and highest cold hardiness," indicating that these populations are more adapted to short growing seasons than those in northern Idaho. At similar elevations, growth potential increases and cold hardiness decreases southward.

Genetic variability was found in tests of 143 populations from the the northern Rocky Mountains for traits related to growth, phenology, frost tolerance, *Meria laricis* needlecast resistance, and survival. Up to 34 percent of the variation was related to geography, and latitude and altitude also affected patterns of variability. In general, northern or high-altitude populations had lower growth potential, needlecast tolerance, and survival rates. Variation within a given geographic area was minimal except where altitude also varied by approximately 1,640 feet (500 m). Regression analyses indicated that the mildness of climate and, to a lesser degree, the amount of precipitation affect the degree of genetic differentiation (Rehfeldt 1992).

2. Seed Transfer

Rehfeldt (1992) reported that western larch genetic variability has not been degraded by harvest and management activities and that by designing seed transfer guidelines to mimic natural patterns of variation within and among populations, reforestation programs can maintain and perhaps enhance genetic variability. Yanchuk (1997) discusses approaches to gene conservation for 23 conifer species, including western larch, in British Columbia.

In general, seed zoning should resemble natural variation patterns. Rehfeldt (1982, 1992) suggests that seed transfer be limited to within 740 feet (225 m) of elevation and plus or minus one contour of the seed source within broad geographic zones. Breeding zones should be within two contours. In British Columbia recommended seed transfer guidelines are slightly different: seeds may be transferred up to two degrees north, one degree south, three degrees west, or two degrees east of the source. Transfer 980 feet (300 m) upward or 490 feet (150 m) downward from the elevation of the source is acceptable, and all transfer should occur within a given biogeoclimatic zone (British Columbia Minstry of Forests 1989).

Preliminary data indicate that six to 10 percent increases in eight-year height may be achieved by transferring fast-growing provenances from northern Idaho to northwestern Montana, but long-term data are needed before broad implementation of such transfers (Rehfeldt 1992). Western larch from British Columbia planted in Sweden did not perform as well as other larch species studied (Martinsson 1992, 1995).

3. Hybrids

Western larch-alpine larch hybrids

Although similar in distribution, western larch and alpine larch usually are separated in elevation by 980 to 1640 feet (300-500 m) (Carlson 1995; Carlson and Blake 1969; Carlson and others 1990a, 1991; Pâques 1992; Schmidt 1995; Schmidt and Shearer 1990). Putative hybrids result where distributions of both species overlap (Carlson 1995; Carlson and Blake 1969; Pâques 1992; Schmidt and Shearer 1990), such as in the Carlton Ridge Research Natural Area and in the

Cabinet Mountains and Bitterroot Range of Montana (Carlson and Ballinger 1995).

Hybrids of western larch and alpine larch usually have various combinations of parental characteristics. At least three characteristics should be noted before determining whether tree is a likely hybrid, and intermediate pubescence is the most reliable indicator. Other common traits are intermediate bark color and texture, blue-green summer foliage like that of alpine larch, and shiny needles like those of western larch (Carlson 1995; Carlson and Ballinger 1995). Carlson (1995) discusses larch hybrid identification in more detail.

Some hybrids of unusually large diameter and height have been reported, which indicates that hybrid vigor may occur (Carlson and others 1990a, 1991). It has been suggested that hybrids may be more tolerant of cold climates than western larch, making them more appropriate for plantings in cold, moist habitats (Carlson 1995; Carlson and Ballinger 1995). Introgression in natural hybrids of western larch and alpine larch may also play a role in the wide variations in wood quality and volume that have been reported (Carlson and Blake 1966).

Controlled reciprocal crosses (alpine larch pollen to western larch cones and western larch pollen to alpine larch cones) produced viable seed and healthy seedlings (Carlson 1995; Carlson and Ballinger 1995). Greater growth and survival were found in western larch seedlings and hybrids with a female western larch parent (Carlson and Ballinger 1995). No races of western larch have been reported (Schmidt and Shearer 1990).

Other western larch hybrids

Interspecific hybridization of larch has been carried out with many species in an attempt to obtain genetic improvement of the resulting hybrids. Many known larch hybrids are valuable because they combine desirable characteristics of both parents and they also exhibit hybrid vigor (MacGillivray 1969). Hybrids from natural or controlled pollination have been made between western larch and Japanese larch (Carlson and others 1990a; Wang 1971) and European larch (Carlson and others 1990a) Western larch-Japanese larch open-pollinated crosses had low seed set and viability, but hybrid seedling grown in greenhouse had significantly greater height (Wang 1971).

4. Genetic Engineering

"Improvement" programs seek to breed trees with enhanced volume growth and wood quality, while maintaining genetic diversity of populations. Fins and others (1984) reported that on excellent sites in northern Idaho, tree improvement programs are likely to profit at four and five percent discount rates, and on good sites they will profit at four percent discount rates.

Jaquish and others (1995) discuss western larch improvement research in the Inland Northwest, which is coordinated by the Inland Empire Tree Improvement Cooperative, the USDA Forest Service's Northern Region, and the British Columbia Ministry of Forests. Issues that have been prioritized for additional research include "seed orchard technology and management, age-age correlations for selected traits, relationships between performance in long-term field tests and early selection trials, the effects of inbreeding on select and no-select traits, interspecific hybridization, realized gain estimates from area-based yield plantings, and integrating the products of biotechnology research."

Artificial breeding can improve cold hardiness and needlecast resistance of western larch, potentially reducing the need for the use of chemicals for the latter (Forest Service 1995). Data from Idaho and Montana indicated that increased growth is associated with increased *Meria laricis* needlecast resistance. However, selecting for increased growth alters natural populations' growth rhythms. Gains in growth of up to 70 percent may be achieved without alteration of growth rhythm and while improving needlecast resistance by selecting for the rate of shoot elongation instead of increased growth (Rehfeldt 1992).

For artifical crossing of western larch and alpine larch, pollen should be collected from alpine larch the previous year and stored frozen since this species produces pollen several weeks after western larch conelets are produced (Carlson and Ballinger 1995). A mechanized system of pollen collection and an electrostatic pollination method have been used for mass production of seeds of hybrid larch (*Larix* x *eurolepis* Henry) in French seed orchards (Baldet and Phillipe 1993; Philippe and Baldet 1992). Dumont-BeBoux and others (2000) discuss a method that has been successfully used to germinate western larch pollen *in vitro*. Successful propagation of 383 parent trees by field grafting has been accomplished (Jaquish and others 1995). Cuttings from western larch trees successfully rooted six percent of the time on average over a three-year period, substantially less than all other species except Dahurian larch. The highest percent rooting for one tree in a single year was 16, which was also considerably lower than other species (Table 7) (Chandler 1967).

Karnosky and others (1995) describe a method for regeneration of genetically transformed European larch using *Agrobacterium rhizongenes* as a vector. Charest and others (1995) discuss technologies useful to larch improvement programs including somatic embryogenesis, cryopreservation, genetic transformation, and restriction fragment length polymorphism.

Table 7: Western larch rooting statistics (Chandler 1967)

	Average % rooting	Highest % for one tree in one year
Larix decidua	21	67
L. leptolepis	48	77
L. x *eurolepis*	53	79
L. dahurica	80	92
L. laricina	32	43
L. occidentalis	6	16
L. olgensis	6	38
hybrids	56	100

G. DAMAGE FROM BIOLOGICAL FACTORS

Though many insects and diseases can affect western larch, damage is usually more severe in other associated species (Fiedler 1995; Schmidt and Shearer 1990; 1995; Shearer and Halvorson 1967). Western larch's deciduous habit enhances tolerance of defoliating pests since it replaces its needles annually anyway. Repeated defoliation, however, slows growth and may affect competitive ability (Arno and Hammerly 1977). Epicormic branching appears to offer help with recovery from disease by replacing damaged branches (Lanner 1995).

Carlson and others (1995) summarize insects, pathogens, and other damaging factors that affect western larch. Models for analysis of insect and disease risks include UPSET and UTOOLS, and the Forest Vegetation Simulator can predict effects of insects and disease on stand growth (Torgersen 2001).

1. Diseases

Important diseases affecting western larch include needlecast caused by *Meria laricis* and needle blight caused by *Hypodermella laricis* (Fiedler 1995; Garbutt 1984; Schmidt and Shearer 1995; Tunnock and others 1969; Garbutt 1996; Navratil and Bella 1988) as well as the brown trunk rot caused by the quinine fungus, *Fomes officinalis*, and red ring rot caused by *Phellinus pini* (Cohen 1967).

A variety of less common fungi also infect western larch (Foster and Wallis 1969; Hepting 1971; Leaphart 1964; Shearer and Mielke 1958). Some of them, such as the shoot blight disease (*Encoeliopsis laricina*) and the fungus *Phacidiopycnis pseudotsugae*, are potentially serious pathogens (Funk 1969; Parks and Flanagan 2001; Schmidt and others 1976; Schmidt and Shearer 1990; Wicker 1965). Most, however, have not caused significant problems to date. In nurseries, some fungal diseases of concern include grey mould caused by *Botrytis cinerea*, needlecast caused by *Meria laricis*, as well as *Fusarium* spp., *Cylindrocarpon* spp., and others that cause damping-off, cotryledon blight, and root disease (James and others 1995).

Although estimates of defect caused by disease and injury for some local areas have been derived (Aho 1966), total effects of most western larch diseases on growth and mortality have not been evaluated (Leaphart and Denton 1961).

Fungi that have symbiotic relationships with western larch include *Boletinus appendiculatus, B. caipes, B. grisellus, B. ochraceoroseus, Cenococcum graniforme, Suillus grevillei,* and *S. luteus* (Laut 1966; Trappe 1962).

Dwarf mistletoe (*Arceuthobium laricis*) is the most serious parasite that affects western larch. Its effects on western larch is described in more detail below, followed by a summary of the literature available regarding fungi that affect western larch.

Dwarf mistletoe

The most damaging disease-causing parasite of western larch is larch dwarf mistletoe (Beatty and others 1997; Schmidt and Shearer 1990, 1995). Dwarf mistletoes are small plants that parasitize many conifers in the West, including the Northern Rocky Mountains (Wicker and Hawksworth 1988), by embedding a network of root-like, absorbent strands into host tissues. This network, called the endophytic system, then extracts water and nutrients from the host. Within one to two years of initial infection, slight swellings become apparent (Beatty and others 1997). In later stages of infection, dwarf mistletoes result in masses of malformed branches and twigs, or "witches brooms," which are generally found in the lower or mid crowns (Beatty and others 1997; Sala and others 2001). Typically the brooms of larch dwarf mistletoe are nonsystemic (Tinnin and others 1982). Over time, as infected trees are deprived of nutrients and water, height growth declines and may stop, foliage becomes sparse and change color, and eventually the treetops begin to die (Beatty and others 1997).

Table 8: Expected 10-year western larch growth reductions from larch dwarf mistletoe infection (Pierce 1960)

Infection level	**Basal area growth reduction (square feet)**
Light (brooming in < 1/3 of crown)	14.18
Medium (brooming in 1/3-2/3 of crown)	41.13
Heavy (brooming in > 2/3 of crown)	68.79

The most widespread and damaging effects of dwarf mistletoes are decreased diameter and height. Slight infections can reduce growth by 25 percent and heavy infections may cause 50 percent growth reductions in young trees (Gill 1935). Wicker (1979) presents data regarding dwarf mistletoe-caused growth reduction, and data regarding basal growth reduction from Pierce (1960) is summarized in Table 8.

Volume loss also occurs as a result of dwarf mistletoe infection. With severe infections, western larch volume growth may decline as much as 50 percent. Drummond (1982) estimated the annual western larch habitat type volume loss in the Montana and northern Idaho (USDA Forest Service Region 1) due to dwarf mistletoes at 20 cubic feet per acre (1.4 m^3/ha) per year, for a total of 15,320 million cubic feet (434 million m^3) per year. Dwarf mistletoe infestations of western larch in the Flathead and Kootenai National Forests in 1980 were 33.7 percent and 15.3 percent, respectively, and annual volume losses were 936 million cubic feet (26.5 million m^3) and 902 million cubic feet (25.5 million m^3), respectively (Dooling and Eder 1981b).

Severe infestations of larch dwarf mistletoe result in significantly greater mortality than in similar uninfected western larch stands. Moderate infestations also increase mortality. Stems of the brooms become increasingly brittle as the disease progresses, and the brooms often break off the tree when winter snowfall becomes heavy, a common cause of mortality (Beatty and others 1997).

Sala and others (2001) found correlations between heavy dwarf mistletoe infections and significant increases in leaf to sapwood area ratios in western larch. This response to infection, along with altered water transport dynamics, led to significantly lower water potential late in the summer. Elevated leaf to sapwood ratios in western larch also increased water use in large trees, which may have effects on soil water availability and, therefore, stand productivity in mature stands toward the end of the growing season (Sala and others 2001).

Dwarf mistletoe also may result in increased vulnerability to insect or other diseases, reduced vigor, reduced seed and cone production, lower timber quality due to knots and burls, and shorter lifespan (Beatty and others 1997; Hawksworth and others 2002; Hawksworth and Weins 1996; Kimmey and Graham 1960; Schmidt and Shearer 1990; Taylor and others 1993; Weir 1916a).

The lateral spread rate of larch dwarf mistletoe has been estimated at 1.5 to two feet (0.5-0.6 m) per year (Beatty and others 1997), and one study showed that mistletoe seed can be ejected as far as 45 feet (14 m) (Smith 1966). Therefore, 50 evenly spaced, diseased trees per acre (20 trees/ha) (such as a residual overstory) could infect a whole acre of understory trees with just one good crop of dwarf mistletoe seeds (Schmidt and Shearer 1990). Since understory trees are easily infected by dwarf mistletoe seeds from overstory trees, the disease spreads more rapidly in multistoried stands (Beatty and others 1997). However, if stands are very dense, dwarf mistletoe seed production may be lower due to limited light and low host vigor, and seeds may be trapped in the crown (Schwandt 1977). Well-stocked, even-aged, mixed species stands minimize the spread of dwarf mistletoes (Schwandt 1977).

Larch dwarf mistletoe is able to rapidly intensify in western larch forests once a source is established, even in lightly stocked (spacing 20 by 20 feet (6 x 6 m)) stands (Wicker and Wells 1983). For example, in a thinned and artificially inoculated western larch stand, larch dwarf mistletoe intensification was slow for the first six years, but increased five- to ten-fold over the subsequent three years. No lateral spread was detected for the first six year period, but over the next three years, lateral spread averaged 11 to 16 feet (3.5-4.9 m) with a maximum of 21 feet (6.4 m) (Wicker and Wells 1983).

In addition to dispersal by explosive fruits, birds are important vectors for the dispersal of larch dwarf mistletoe seeds. They have been observed carrying infected nest material to new host trees and are thought to transport seeds externally. No evidence that they feed on dwarf mistletoe seeds was found (Hawksworth and others 2002; Hawksworth and Weins 1996; Zilka and Tinnin 1976).

Larch dwarf mistletoe infections are widespread throughout most of the natural range of western larch (Beatty and others 1997; Dooling 1971; Foster and Wallis 1969; Hawksworth and Wiens 1972; Russell 1971; Taylor and others 1993; Weir 1916a), and its ecological and economic impacts can be substantial (Van Sickle and Smith 1979; Hawksworth and Wiens 1996). Maps of larch mistletoe distribution in British Columbia (Baranyay and Smith 1972) and Montana (Dooling and Eder 1981a) are available.

Sixty to 80 percent of western larch forests in eastern Washington, northern Idaho and western Montana have dwarf mistletoe infections (Wicker and Hawksworth 1988). Eighty-six percent of the larch stands in northeastern Washington are infected (Graham and Frazier 1962). Bolsinger (1978) estimated that approximately 47 percent of the western larch forest type was infected by dwarf mistletoe in Oregon and Washington around 1972, with western larch being the most heavily affected. Between 20 and 79 percent of the stands in the lower panhandle of Idaho are infected (Graham 1960). About 36 percent of the stands in west-central Montana are infected (Graham 1964). Surveys indicate that 35 percent of western larch forests are infested with larch dwarf mistletoe in the Inland Empire and that 50 percent of eastern Oregon's and Washington's are infested (Beatty and others 1997). Overall, approximately 38 percent of western larch in Montana and northern Idaho were infected in 1982 (Drummond 1982).

Although dwarf mistletoe infection is heaviest in older trees, no age class is immune. Infected trees as young as four years have been observed by Weir (1916b), and Wicker (1965) has shown that four-month-old larch can be successfully inoculated. But infection in young trees is usually light because the trees present a small target for the dwarf mistletoe seed (Wicker and Shaw 1967). Also, snow, wind, rain, insects, and molds remove most dwarf mistletoe seeds before they infect the seedling (Mathiasen 1998b; Wicker 1967).

A survey of western larch from northern Idaho and western Montana found dwarf mistletoe infections were rare in trees younger than seven years old or less than 5 feet (1.5 m) tall. Most infection occurred before age 14 or 13 feet (4 m) in height. The intensity of infection and proximity (within 39 feet (12 m)) of overstory larch significantly affected the age and tree height at the time of initial infection (Mathiasen 1998b).

Surveys also show that the largest trees in residual overstories are infected most heavily and they in turn are the source of infection for the younger larch (Graham and Frazier 1962). Infection is six to seven times heavier in sapling and pole stands with an overstory of older trees left from fires or logging than in similar stands with no overstory. The likelihood of seedling infection depends on seedling age, stand density, and the level of infection in the overstory (Beatty and others 1997).

The six-class Dwarf Mistletoe Rating system (DMR) is the most widely used mistletoe intensity evaluation system in North America. Values one and two reflect light infection, three and four are moderate, and five and six indicate heavy dwarf mistletoe infection. Hawksworth (1977) describes the applications and limitations of the system.

Though many dwarf mistletoe species infect only one species, some occur on several different species within a genus. Rarely, they infect conifers in different genera. Larch dwarf mistletoe is more host specific than hemlock dwarf mistletoe and less host-specific than lodgepole pine dwarf mistletoe and Douglas-fir dwarf mistletoe (Smith 1974).

Western larch is the principal species infected by larch dwarf mistletoe. Other susceptible species include lodgepole pine, western white pine, scots pine, subalpine fir, Engelmann spruce, mountain hemlock, ponderosa pine, Pacific silver fir, whitebark pine (Beatty and others 1997; Dooling and Eder 1981a; Graham and Leaphart 1961; Hawksworth and Wiens 1972; Kuijt 1953, 1954;

Mathiasen and others 1995a; Mathiasen 1998a; Schwandt 1977; Tinnin and others 1982; Weir 1918). Douglas-fir and western redcedar are immune to larch dwarf mistletoe (Beatty and others 1997; Mathiasen 1998a; Schwandt 1977). Schwandt (1977) classified western hemlock as immune, and though Mathiasen (1998a) found no western hemlock trees infected with larch dwarf mistletoe, reports from Washington led to its characterization as a rare host. No valid reports of larch dwarf mistletoe parasitizing alpine larch are known (Mathiasen and others 1995b).

Artificial inoculations of hemlock dwarf mistletoe on western larch have been successful, although the parasite's slow growth indicates that western larch is not an ideal host (Smith 1970, 1971). Western larch is resistant to lodgepole pine dwarf mistletoe, Douglas-fir dwarf mistletoe (Baranyay and Smith 1972; Schwandt 1977). Kujit (1955) reported that western dwarf mistletoe does infect western larch, but Schwandt (1977) listed western larch as immune.

Historically, dwarf mistletoe has been considered a pest, and suppression has been the primary management goal. However larch dwarf mistletoe's importance as an ecological component of western larch forests has recently been emphasized (Hawksworth and others 2002; Hawksworth and Weins 1996; Taylor

1995; Wicker and Hawksworth 1988). Where timber production is a management goal, reduction of dwarf mistletoes may be a useful practice, but in other stands control may be uneccessary (Taylor 1995). For example, since mistletoe brooms provide important wildlife habitat (Bull and others 1997), it may be undesirable to remove infected trees from areas where wildlife management is important (Mathiasen 1998b). Wicker and Hawksworth (1988) discuss the ecological role of dwarf mistletoes in more detail and suggest incorporating information regarding weaknesses in the mistletoe life cycle into control practices.

Where control is desired, management methods under development include biological, chemical, and cultural practices (Hawksworth and others 2002; Hawksworth and Weins 1996). In British Columbia, control measures have included aerial and ground surveys, stand thinning, residual removals, treatment of advance regeneration, fringe planting, scarification, and selection cutting (Van Sickle and Smith 1979).

Due to the high degree of host specificity and relatively slow rates of spread, proper silvicultural methods provide the most efficient treatments for dwarf mistletoe (Baranyay and Smith 1972; Schmidt and Shearer 1990, 1995; Schwandt 1977; Taylor 1995; Wicker and Hawksworth 1988). The best results are produced with clearcuts of 20 acres (8 ha) or larger (Taylor 1995), but current pressures to balance other uses and values limit the application of this treatment (Taylor and others 1993).

Since western larch saplings are usually infected before they are 15 years old or 13 feet (4 m) tall when growing near infected overstory trees, removal of infected western larch overstory before young larch in close proximity reach age seven or three feet (1 m) tall is recommended (Mathiasen 1998b; Schwandt 1977), and retreatment within three to five years can eliminate remaining infections (Schwandt 1977).

Studies are underway to evaluate thinning-dwarf mistletoe relationships. Quantitative data are not yet available, but preliminary observations indicate that vigor of the dwarf mistletoe is enhanced by the increased amount of available light in the thinned stands. However, even a moderate level of dwarf mistletoe infection did not prevent western larch growth acceleration following thinning (Schmidt and others 1976).

Taylor and others (1993) found that intensification, spread, and effects of larch dwarf mistletoe did not vary significantly between the following treatment types: logged and thinned, logged and unthinned, unlogged and thinned, and unlogged and unthinned. However, understory infection level was substantially affected by infection level of the overstory. And Wicker and Hawksworth (1991) reported that inoculations of larch dwarf mistletoe in Coram Experimental Forest spread during the subsequent years in all three stand spacings: eight by eight feet (2.4 x 2.4 m), 14 by 14 feet (4.3 x 4.3 m), and 20 by 20 feet (6.0 x 6.0 m). Seed tree or shelterwood practices when the understory is less than 10 years old or three feet (1 m) tall have been effective when unifected residuals are used or infected residuals are removed (Taylor 1995).

Thinning and sanitation have reduced infestations substantially, resulting in increased yields and a favorable cost-benefit ratio of treatment (Dooling 1974; Dooling and Haglund 1974). Merrill and others (1989) reported that thinning and sanitation had not effectively controlled dwarf mistletoe infection in western larch or Douglas-fir 10 years after treatment on the Flathead Indian Reservation, Montana. Broom pruning may also be effective, but this control measure is only feasible in small areas or for individual trees (Parks and Flanagan 2001).

Fertilizer treatment of western larch did not significantly affect mortality, diameter increment, vigor, live crown ratio, or dwarf mistletoe rating. However, DMR did significantly affect increment, mortality, and vigor, regardless of fertilizer treatment. Mortality ranged from zero in trees with no or light dwarf mistletoe infection to 56 percent with severe infection (Filip and others 2002).

Permanent larch dwarf mistletoe monitoring plots have been established at Growden Area, Colville National Forest, Washington; Coram Experimental Forest, Montana; and Boise-Cascade lands in northeastern Oregon (Hawksworth and Marsden 1990). Additional resources regarding the distribution, biology, identification, effects, and management of dwarf mistletoe species are available (Baranyay and Smith 1972; Hawksworth and Weins 1972; Mathiasen and Blake 1984; Parks and Flanagan 2001; Wicker 1974).

Fungi

Studies on the Priest River and Coram Experimental Forests have shown fungi to be the most destructive of the biotic agents among first-year western larch seedlings (Haig 1936; Haig and others 1941; Shearer 1961). Fungi caused greater mortality in seedlings growing on duff than on exposed mineral soil surfaces in full sun or partial shade. Under full shade, however, where temperature did not differ markedly between duff and mineral surfaces, the reverse was true. The results for Douglas-fir were similar to those for western larch except that neither seedbed condition was superior to the other under partial shade.

In general, western larch has moderate resistance to root rot (Williams and Lillybridge 1983). Fungal root diseases, which can affect stand structure, density, composition, function, and yield (Thies 2001), occur in western larch. Typically they do not cause much mortality after age 20 or 30 in western larch (Hagle and Goheen 1988; Shaw and Kile 1991).

Some decay fungi do affect western larch, but living western larch are more resistant than nonresinous conifer species such as the true firs and hemlock (Etheridge 1973), and decay from fungi is relatively rare (Byler and others 1994). A summary of the available literature regarding fungi that affect western larch follows.

Compared to some other conifers of the northern Rocky Mountains, western larch is relatively resistant to root rot caused by *Armillaria ostoyae.* It is more resistant to infection by *A. ostoyae* than western white pine, ponderosa pine, Douglas-fir, and grand fir (Entry and others 1992). After inoculation of saplings of five western conifer species by *A. ostoyae,* western larch had the greatest height and diameter growth as well as the highest concentrations of phenolic compounds and protein-precipitable tannins in the root bark (Entry and others 1992).

Though in six- to eight-year old western larch trees, infection advanced quickly, in older trees (18-19 years and 85-95 years) lesions did not spread

(Robinson and Morrison 2001). Typically, western larch mortality from root disease, including *A. ostoyae,* declines around 20 to 30 years of age (Hagle and Goheen 1988; Shaw and Kile 1991).

Stressed trees, such as those with limited light or nitrogen availability, are more susceptible to infection by *A. ostoyae.* Seedlings that are most susceptible may have lower concentrations of phenolic compounds and higher concentrations of sugars in root bark (Entry and others 1991). This may result in increased sugar availability to the fungus for degradation of phenolic compounds and host tree invasion in weakened individuals (Entry and others 1991, 1992).

In the northern Rocky Mountains, *Armillaria* spp. rhizomorphs were found on 22 of 51 (43 percent) of healthy western larch trees (McDonald and others 1987b). Of 22 stands in Idaho and western Montana, a higher proportion of planted trees than natural regeneration were infected or killed by *Armillaria* (Byler and others 1985). McDonald and others (1987a) found that as habitat type productivity increased, presence of *Armillaria* decreased. In Idaho, defoliation by larch casebearer was associated with increased *Armillaria* root disease in western larch (Tunnock and others 1969).

Morrison and others (2000) studied relationships between aboveground symptoms and belowground incidence of *A. ostoyae*. The percentage of colonized stumps in and near study plots was related to belowground incidence. Climatic regions significantly affected infection intensity, host reaction, and the percentage of trees with aboveground symptoms.

Due to its resistance after age 20 to *A. ostoyae,* planting of western larch is recommended for sites infested by the fungus. Alternating rows of western larch and western redcedar may help minimize mortality in young western larch (Morrison and others 1988). Likewise, selective logging in mixed conifer forests where western larch occurs can help facilitate regeneration of Douglas-fir and true fir, species that are more susceptible to *A. ostoyae* (Shaw and Kile 1991).

Botrytis blight, caused by the fungus *Botrytis cinerea* is a major disease of western larch seedlings, particularly those grown in containers in greenhouses (James 1984). High humidity and cool temperatures, common greenhouse conditions, are favorable to infection and spread of this pathogen (James 1984).

Other conifers are infected by the fungus, but western larch is one of the most susceptible (James 1984). Substantial accumulations of foliage at the base of western larch trees at the end of the growing season provides easy infection sites for the spores, which are typically airborne. From there, the disease can spread to stems of adjacent seedlings, resulting in infection or death. As clusters of seedlings become infected, more *Botrytis* sprores are produced and more seedlings will become infected (Dugan 1988; James 1984). Studies by Dugan (1988) and Dugan and Blake (1989) found that "direct penetration occurred most often on succulent needles," and "germination, hyphal growth, and stomatal entry were especially enhanced on senescent needles" (Dugan 1988).

Combinations of fungicides, which protect from infection, and cultural practices, which alter environmental conditions, are advised for reducing seedling susceptibility to infection by *B. cinerea* (James 1984; James and Genz 1983; James and others 1995). Fungicides that have effectively controlled the fungus on container-grown western larch include iprodione, chlorothalonil, captan. Benomyl and dicloran were not as effective, and vinclozolin resulted in severe phytotoxicity to containerized, but not bare-root, seedlings. All fungicides mentioned above reduce seedling height growth (James and Genz 1983; James and Woo 1984). Other tests of captan and dicloran (Dugan 1988) were not effective (Dugan 1988; Dugan and Blake 1989; James and others 1983). The pathogen has developed resistance to some fungicides that were used in the past (James 1984). Cultural practices that can help control *Botrytis* blight include better sanitation, ensuring adequate air circulation, and reducing irrigation. Biological control agents are under investigation (James and others 1995).

Western larch seedlings are susceptible to blight caused by *Colletotrichum gloeosporioides*, though less so than western hemlock and mountain hemlock. Symptoms appeared within five days of inoculation and peaked after 16 days. Seventy-five percent of inoculated seedlings were affected by the blight, which casues sever needle blanching, followed by needles needles turning brown then reddish-brown. The fungus may also affect shoots (Griffin and others 1987).

Cylindrocarpon spp. commonly infect cortical tissues on seedling roots, though they are usually not problematic (James and others 1995). Like *Fusarium* (see description below), *Cylindrocarpon* may infect containerized western larch seedlings (James and Gilligan 1988a; James and Woolen 1989; James and others 1995), but James and Gilligan (1988a) reported that the presence of the fungus did not affect seedling height. *Cylindrocarpon* populations have been successfully reduced by cleaning stryoblock seedling containers with hot water 154° Fahrenheit (68° C) and a dilute bleach-detergent solution (James and Woollen 1989). Steam treatment significantly reduced *Cylindrocarpon* populations in styroblock containers, but large fungal populations were still present (James and Gilligan 1988a).

Sporophores of *Echinodontium tinctorium* were found on western larch in Lincoln County and Sanders County, Montana, for the first time in 1992 and 1993, respectively (Taylor and others 1996). The fungus was also found on western larch in northern Idaho mixed conifer stands in 1974 and 1974, where it was more common in stands dominated by grand fir (Hobbs and Partridge 1979).

Species of the genus *Fomes* to which western larch is susceptible include *F. annosus* (Hagle and Goheen 1988), the white picket rot *F. nigrolimatatus* (Partridge 1968), and the brown trunk rot caused by *F. officinalis,* also known as quinine fungus or quinine conk. The latter is the most serious rot that affects western larch (Boyce 1930; Partridge 1968).

Fusarium spp. are among the most important root pathogens that affect western larch (James and others 1991b), particularly in nurseries. Seven species have been identified in this genus, but only *F. avnaceum, F. oxysporum,* and *F. sporotrichiodes* are associated with western larch (James 1987b). Western larch, as well as

Douglas-fir, Engelmann spruce, and true fir, are especially susceptible to damage from this pathogen, and considerable variability between seedlots has been reported (James 1985b, 1987b; James and others 1990a).

These fungi frequently colonize the inner walls of styroblock and Ray Leach® pine cell containers, and they tend to be most concentrated near the bottom of the cells. Infection of as many as 95 percent of sampled containers has been reported (James 1988; James and others 1988). Cells that have been stored for several months may have high concentrations of *Fusarium* (James and Gilligan 1988b), and colonized containers may serve as a source of inoculum for the next seedling crop (James and others 1988).

Because *Fusarium* causes damping off in young seedlings and results in root diseases in older seedlings (James 1986, 1987b; James and others 1991a), it can substantially reduce seedling production (James and others 1991b). Older containerized seedlings that are stressed may be particularly susceptible to severe infection (James and others 1995).

James (1986, 1987a) found *Fusarium* on as many as 90 percent of seedlings and the fungi have been associated with symptomatic and asymptomatic seedlings' roots. In seeds, the fungi are found on the seedcoat and within the endosperm (James 1987b), and are associated with nongerminated seeds (James 1987a).

Effective management of *Fusarium* root disease includes practices which reduce inoculum levels, enhance host resistance, encourage competing organisms, and minimize the use of chemical fungicides (James and others 1990a; 1991b). In nurseries where *Fusarium* colonization is suspected, screening is recommended prior to sowing and sterilization treatments (James 1987a). Conditioning seeds under running, rather than standing, water may reduce the spread of propagules and minimize seedcoat contamination. Seeds have been treated with fungicides to reduce damping-off, but reports of toxicity have reduced their use (James 1987b). Periodically removing infected seedlings may also help reduce losses (James 1985b).

Cleaning with hot water and dipping bleach solution reduced *Fusarium* in containers, but did not eliminate the fungi (James and Gilligan 1988; James and others 1988; James and Woolen 1989). Such treatment has removed *Fusarium* from pieces of seedling roots that had penetrated container walls (James and Woolen 1989). Hydrogen peroxide has also been used as a sterilant, though consistent results have not been obtained. Reductions in colonization from 86 percent of 350 leach pine cells to 50 percent after cleaning have been reported (James 1987b).

Methyl bromide fumigation was more effective than hot water in treating pine cells, but not stryroblock containers (James and others 1988). Fumigation with a mixture of methyl bromide and chloropicrin did eliminate *Fusarium* from western larch seedlings. Granular dazomet fumigation was initially effective, but the fungi reinvaded the soil (James and others 1990b).

James (1987b) discussed *Fusarium* species, associated diseases, and control methods, and Lock (1973) described the distribution, life history, symptoms, damage, and control of *F. oxysporum.*

Heterobasidion annosum is widespread in the northern Rocky Mountains (Williams 1989). It causes decay, stain, and breakage resulting in reduced strength and wood value (Thies 2001), and trees weakend by dwarf mistletoe prior to infection may die (Williams 1989). Though western larch is susceptible to *H. annosum,* from "P-group" (Thies 2001), infection is relatively rare (Williams 1989), and the species has been characterized as *H. annosum*-resistant (Filip 2000; Filip and others 2000). Relative to a thinned stand of grand fir, western larch stumps had low levels of *H. annosum* infection (Filip and others 1987), and the disease was found in two commercially thinned western larch stands at frequencies of only five to six percent (Filip and others 1987). Due to its resistance to *H. annosum* western larch is recommended for areas where root disease is causing mortality (Filip and others 1987).

Hypodermella laricis (Cohen 1967) causes needle blight on western larch (Ostry and others 1990), but it is not considered a serious pest (Garbutt 1996). The disease occurs in North America as well as central Europe, but tamarack is the only other North American species known to be affected by this pathogen (Vanderwal 1970).

Because mature needles are immune to the disease (Vanderwal 1970), infection by the short-lived spores of this fungus occurs within a roughly two-week period in early spring immediately after needles emerge. Needles turn red and die approximately six weeks after infection (Vanderwal 1970), from mid-May to mid-June (Dubreuil 1982), and heavily infected stands will appear entirely brown and dead. The appearance of the initial fruiting bodies (pycnidia) in the form of elliptical black spots on needles at this time is an identifying characteristic of this fungus. More obvious fruiting bodies (hysterothecia) will appear later in the summer, and spores develop in late summer and fall (Hubert

1954; Vanderwal 1970).

Another identifying attribute of *H. laricis* is that infected trees do not shed their needles. Instead needles are retained until at least the following year (Dubriel 1982; Hubert 1954; Vanderwal 1970). After spring rains, the spores are released from the fruiting bodies and dispersed by the wind or splashing rain to attach to and infect young larch needles when and if the conditions are suitable (Hubert 1954; Vanderwal 1970). Dubreuil (1982) discusses the life cycle of *H. laricis* in more detail.

Usually *H. laricis* does not cause death, and crowns regenerate fully by the following year unless infection occurs in several consecutive years, but diameter and height growth losses may be substantial (Dubreuil 1982; Garbutt 1996; Hubert 1954; Vanderwal 1970). Loss of diameter growth is generally proportional to the extent of defoliation, and height growth losses result from death of terminal shoot buds (Dubreuil 1982). Root mortality from *H. laricis* infection may occur after four or more years of 70 percent defoliation and may increase susceptiblity to root pathogens (Dubreuil 1982). Rarely does the disease affect timber values (Hubert 1954).

Though *H. laricis* is found on some trees every year, epidemics occur about once per decade and are generally related to moist spring weather, which is conducive to spore production and infection (Dubreuil 1982; Hubert 1954). Drought conditions limit the spread and infection of this fungus (Vanderwal 1970). Bordeaux mixture or lime sulphur, applied one week before budbreak and until two to three weeks after, has been used to minimize damage to western larch nursery seedlings and ornamentals (Dubreuil 1982; Vanderwal 1970).

Melampsora medusae foliage rust, also called the larch-willow rust, has the option of alternating between western larch (primary host) and willow (secondary host) hosts, though how it is able to survive for several consecutive years without its primary host is not fully understood (Hunt 1978; Toole 1967). This fungus was first found on western larch in the Northwest in 1991 (Newcombe and others 1994). Yellow or orange discolorations on needles occur with this rust, as with other foliage rusts. *Melampsora* rusts, however, produce a different type of aecia, which appears flat when magnified, than other rusts. Also aeciospores of this pathogen are fully exposed, not covered or membrane-contained (Hunt 1978). Locating western larch nurseries away from willows may help decrease the chance of spring infection by *Melampsora* (Hunt 1978).

Meria laricis causes needlecast in western larch and has been reported in Idaho, Montana, Washington, and British Columbia (Ostry and others 1990). In British Columbia, it is the most important disease that affects container-grown western larch (Garbutt 1996). Whether or not this fungus was introduced from Europe is uncertain (Hubert 1954).

This pathogen initially discolors small portions of needles, usually but not always the tip, and eventually entire needles turn brown and fall off two to four weeks after infection (Cooley 1981b; Dubreuil 1982; Knapp 1983; Ostry and others 1990). Unlike *Hypodermella laricis, M. laricis* will continue to cause defoliation as long as rain continues (Dubrueil 1982; Hubert 1954). Fallen needles provide overwintering habitat for the pathogen, often resulting in more severe infection in the following year unless seedlings are relocated (Cooley 1981b; Knapp 1983).

Seedlings are easily infected by the *M. laricis* because their needles are closer to diseased, previously cast needles on the ground (Garbutt 1996). Likewise, lower branches of larger trees are more prone to infection (Hubert 1954). Germinating seedlings may not display symptoms of *M. laricis* until late July, but two-year olds may have symptoms by late May and throughout the summer. Needle shedding on older trees typically starts by mid-July (Ostry and others 1990). Western larch is apparently somewhat tolerant of the disease, and most seedlings survive after being relocated away from heavily infected nursery beds (Cooley 1981b). Two-year old seedlings are more susceptible to damage than older or younger individuals (Bloomberg 1985; Cooley 1984).

Weather conditions largely determine the extent of *M. laricis* infection. Spore production, dispersal, and germination only occur under moist conditions (Garbutt 1996; James 1985a), and above average spring temperatures facilitate spread and infection. Because several life cycles occur in a season, the disease can spread rapidly when conditions are suitable (James 1985a; Ostry and others 1990).

Like *H. laricis*, the other significant needle disease of western larch, *M. laricis* does not usually cause death without several years of successive infection, but can result in height and diameter growth losses (Hubert 1954; Ostry and others 1990). Unlike *H. laricis*, however, *M. laricis* does not kill short shoots and the fruiting bodies are too small to detect without the aid of a microscope (Hubert 1954).

Fungicides which have effectively reduced *M. laricis* in nurseries include benomyl, maneb, and chlorothalonil (Ostry and others 1990). Cooley (1981b) reported the best results with benomyl and maneb, followed by ziram, ferbam, and vinclozolin. Bordeaux mixture or lime sulphur may also be effective (Cooley

1981b; Garbutt 1960). Schonohar (1958) found that copper oxychloride, captan, and zineb helped control *M. laricis*, though copper oxychloride was slow to take effect and caused some needle browning.

Fungicides were not effective at reducing *M. laricis* infections in the USDA Forest Service Nursery in Coeur d'Alene Idaho in 1983 due to high levels of inoculum and cool, moist weather conditions. However, after fungicide treatments in 1984, when summer weather was warm and dry, no infection was present (James 1985a). In order to minimize inoculum levels and limit infection of developing needles, fungicide treatment should begin in early spring and continue until warm, dry conditions are prevalent (Cooley 1981b; James 1985a).

Transplanting infected one-year old seedlings to disease-free areas (Garbutt 1960; Ostry and others 1990) and cultivating to bury dead needles (Garbutt 1960) is recommended. Cooley (1981b) reported western larch seedling survival rates of 85 percent three months after outplanting. Growing seedlings outside of the disease's range may be the most effective control (Garbutt 1960). Control of *M. laricis* is not necessary or practical in forests (Hubert 1954; Knapp 1983). Schonohar described effects of *M. laricis* on western larch, and Cooley (1984) and Hubert (1954) discussed methods for minimizing *M. laricis* infections in nurseries.

Western larch is highly susceptible (three to nine percent survival rate) to *Mycosphaerella laricina,* a defoliating fungus that has been imported to the United States. The pathogen may completely defoliate western larch, and needle regrowth may also be infected. This fungus may pose a serious threat to western larch if it is introduced into the Northern Rockies, though tests have not been conducted under the climate conditions in this range (Ostry and Nicholls 1989; Ostry and others 1985)

Phellinus pini (red ring rot) decays western larch heartwood, as well as that of most other western conifers. At first a red stain appears, then "white, spindle-shaped pockets of decay" that run parallel to the wood grain, and finally the wood takes on a "honeycombed appearance" (Parks and Flanagan 2001).

Western larch is considered moderately susceptible to laminated root rot caused by *Phellinus weirii* (Thies 2001), though it is highly resistant to the disease (Filip and Schmitt 1979; Morrison and others 1988). A study of 1,527 trees of six conifer species, including western larch, east of the Cascades in Oregon and Washington found that morality was the most common indicator of infection in susceptible species and internal decay indicated infection in resistant species (Filip and

Schmitt 1979). In mixed conifer stands of northern Idaho, *P. weirii* was found on western larch in 1974 and 1975 in stands above 4,920 feet (1,500 m) elevation, though it occurred most often on western redcedar (Hobbs and Partridge 1979). Western larch mortality from *P. weirii* decreases after 20 to 30 years of age (Hagle and Goheen 1988). Planting of lodgepole pine is recommended for sites infested by *P. weirii* (Morrison and others 1988). If *Armillaria ostoyae* is also present, western larch should be planted as well (Morrison and others 1988).

Studies of bare-root conifer seedlings' tolerance to root disease caused by *Phytophthora* spp. indicated that western larch is highly tolerant of *P. cactorum, P. cryptogea, P. drechsleri, P. megasperma and P. pseudotsugae*. No western larch seedlings were killed and *Phytophthora* was recovered from 55 percent of the inoculated seedlings (Campbell and Hamm 1989).

Western larch seedlings are susceptible to the *Pythium* spp. root pathogens (James and others 1995). These fungi are most damaging in bare-root beds with poor soil drainage. Unless container-grown western larch are overwatered or have poor soil drainage, they are usually not affected by *Pythium* (James and others 1995).

In an Idaho nursery, reductions in western larch seedling height were greatest during the second growing season and were related to higher soil populations of *P. ultiumu* and *P. debaryanum.* In addition, reduced seedling height was significantly correlated seedlings' proximity to irrigation structures. Removal of irrigation structures and ensuring adequate soil drainage were recommended (James and others 1991a). Fumigating with granular dazomet or a combination of methyl bromide and chloropicrin was effective at eliminating *Pythium* from western larch seedlings. However, soil treated with dazomet was reinfected by *Pythium* during the subsequent two-year crop cycle (James and others 1990b).

The European larch canker fungus, *Trichoscyphella willkommii,* can infect vigorous and non-vigorous western larch and other larch species. Though the fungus can infect trees at any time of year, summer inoculations are less likely to result in infection (Hahn and Ayers 1943). One year after planting western larch in infected areas of New Brunswick, no symptoms of the disease were found (Ostaff and Newell 1986). The pathogen is common in Finland (Kurkela 1970). No reports of this fungus in western larch's natural range are known.

After inoculation with *Verticicladiella penicillata* (Grosm.) Kendrick isolated from ponderosa pine roots, western larch roots became infected, though no mortality occurred within the 160-day test period (Mielke 1981).

Ray rot caused by *Polyporus berkeleyi* (Partridge 1968), *Sarcotrochila alpina* (Molnar and others 1972), and *Trichaptum abietinum* (Filip and others 1987) have also been reported on western larch.

2. Insects

Larch casebearer (*Coleophora laricella*) and western spruce budworm (*Choristoneura occidentalis*) are the most damaging insect pests to western larch. The most damaging effect of larch casebearer is loss of growth, which may weaken trees, predisposing them to mortality (Denton 1979). Western spruce budworm affects the form of western larch in western Montana, and height growth may be reduced 25 to 30 percent (Fellin and Schmidt 1973).

Other insect pests that affect western larch are the larch sawfly (*Pristiphora erichsonii*) and larch bud moth (*Zeiraphera improbana*) (Fiedler 1995; Schmidt and Shearer 1995). Occasionally, western larch is damaged by western larch sawfly (*Anoplonyx occidens*), the two-lined larch sawfly (*Anoplonyx laricivorus*), or the larch looper (*Semiothisa sexmaculata incolorata*). And while bark beetles do not usually threaten the species, the Douglas-fir beetle (*Dendroctonus pseudotsugae*) may attack stressed trees. The engraver beetle (*Ips plastographus*), the larch engraver (*Scolytus laricis*), and the false hemlock looper (*Nepytia canosaria*) also cause occasional damage (Schmidt and Shearer 1990).

Species that damage seed cones include the larch cone maggot (*Strobilomyia laricis*), western spruce budworm larvae, woolly adelgids (*Adelges viridis*), and cone midges (*Resseliella* spp.) (Jenkins and Shearer 1989; Shearer and Carlson 1993; Shearer 1984b).

Studies have shown that exotic forest pests can be introduced to North America via unprocessed log imports from Siberia and the Soviet Far East. Mitigation measures are recommended (Forest Service 1991; Goheen and Tkacz 1995).

Defoliating insects

Larch casebearer

Larch casebearer (*Coleophora laricella*) was once considered the most serious pest of western larch (Cochran and Seidel 1999) and the second most important defoliator in the Inland Empire (Intermountain Forest and Range Experiment

Station 1963a). Although eggs may be laid on several other conifers, apparently only those on western larch can complete the full life cycle (Sloan and Coppel 1965).

One generation of larch casebearers are produced per year. Larvae overwinter within "cases" attached to needles. Emergence and feeding coincides with needle growth in the spring (Dawson 1971; Knapp 1983). After pupation, adult moths emerge in early July, and eggs are laid on the undersides of the needles (Dawson 1971; Knapp 1983). Studies in Idaho indicate that larch casebearer may preferentially lay eggs on exposed, rather than shaded, branches (Brown 1977; Brown and Kulhavy 1978a). Larvae hatch directly through the egg shell and into the needle, where they feed for about a month. After constructing a case from the hollow needle, larvae move about freely and mine other needles until the first frost. At this time, the larvae shed their needles, construct new cases, and attach themselves to twigs with silk thread. Clusters are usually found near the base of needle fascicle spurs (Dawson 1971; Knapp 1983).

Long (1988) reported low larch casebearer densities in the upper crown. No preference was found for tree height, height in crown, or aspect of larch casebearer pupal populations in western larch trees in northern Idaho (Flanagan 1984; Flavell 1979). Long and Theroux (1979) reported that overwintering larvae in northern Idaho tended to cluster on the distal tips of branches, and were found on roadside trees as well as those within stands.

Feeding larvae may be active by mid-April at low elevations, but may not become active until mid- to late May at higher elevations (Ryan 1974b; Ryan 1975). Ryan (1974a) found that larvae at 4,000 feet (1,219 m) developed faster than those at higher or lower elevations. Fall activity, however, appears to be determined by day length rather than altitude (Ryan 1975).

This defoliator, of European origin, is found worldwide on nearly every species of larch (Schmidt and others 1976). It was first recorded in North America in Massachussetts in 1886, and it spread to central Minnesota and southeastern Manitoba (Andrews 1966). It was discovered in 170 square miles (440 km^2) of western larch forests near St. Maries, Idaho, in 1957 (Andrews 1966; Denton 1958, 1965). With no natural controls in the West, the casebearer population built up and spread very rapidly. By 1963, the range had expanded to more than 7,500 square miles (19,425 km^2) in the Idaho panhandle, northern Washington, and northwestern Montana. In 1966, it was collected near Rossland, British Columbia (Andrews 1966), and by 1970 the insect had infested more than half of the western larch forest type (Denton 1972; Tunnock and Ryan 1985). By 1982 the moth was distributed throughout western larch's range (Tunnock and Ryan 1985), severely limiting growth and survival of the tree (Schmidt and Shearer 1995).

The larch casebearer is generally not found in high concentration above 4,920 feet (1,500 meters) elevation or at latitudes beyond 50 degrees north (Long 1988). No major outbreaks have occurred since the initial epidemic (Byler and others 1994), and population flare ups that do occur tend to be short-lived and cause little if any direct mortality (Schmidt and Shearer 1990, 1995).

Discolored, hook-shaped needles in May, cigar-shaped pupal cases in June in needle clusters, moths flying about host trees in July, and larval cases clutered at twig spurs in winter are all indications of larch casebearer presence (Dawson 1971; Ferris 1995). Most damage is caused by spring feeding of the fourth-instar larvae. Hollowed-out needles turn light-green to straw-colored with light infestations and become hooked shaped as they dry out. With more heavy infestations, the needles die shortly after they appear, and trees may take on a red-brown, scorched appearance. Groups of damaged trees will be visible from a distance by early summer (Dawson 1971; Ferris 1995; Intermountain Forest and

Range Experiment Station 1963a; Ryan and others 1987; Tunnock and Ryan 1985).

Little tree mortality directly attributable to the casebearer occurs because western larch trees can tolerate defoliation better than most other conifers (Tunnock and Ryan 1985). However, vigor loss and serious suppression of terminal and radial growth may occur, especially with repeated defoliation (Dawson 1971; Intermountain Forest and Range Experiment Station 1963a; Seidel and Cochran 1981; Schmidt and Shearer 1990). Ciesla and Bousfield (1974) developed a quadratic regression equation for predicting defoliation of western larch by larch casebearer larvae.

Studies have shown as much as 92 to 94 percent reduction in radial growth in a four- to five-year period (Tunnock and others 1969; Tunnock and Ryan 1985). Long periods of defoliation have resulted in up to 30 percent loss in volume (Intermountain Forest and Range Experiment Station 1963a). Knapp (1983) found that foliage damage by larch casebearer followed by *Meria laricis* damage can significantly decrease growth, though probably not additively. Continuous growth loss by the combination of these two pests may, however, increase mortality rates.

Four or more consecutive years of defoliation may cause trees to produce fewer and shorter needles. Branch tips, whole branches, tree tops, and even whole trees may dry out with continued severe defoliation (Dawson 1971; Intermountain Forest and Range Experiment Station 1963a; Long 1988; Ryan and others 1987; Tunnock and Ryan 1985). Deformation from epicormic branching is common when main branches are killed (Dawson 1971; Intermountain Forest and Range Experiment Station 1963a; Long 1988). Most mortality occurs in younger trees growing in the open or in edge trees (Ryan and others 1987). After defoliation subsides, tree growth rates quickly return to normal (Long 1988). Reduced vigor resulting from repeated defoliation also can increase susceptibility to secondary insects, such as wood borers, that may finally kill many trees (Seidel and Cochran 1981; Tunnock and Ryan 1985).

Because western larch is shade intolerant, the growth reduction caused by the casebearer can have serious long-term management implications even without mortality. Western larch can maintain itself in mixed stands only as long as it holds a dominant position in the crown canopy. Repeated defoliation slows its growth and places it at a competitive disadvantage. In this way, western larch loses its dominance in the stand and eventually its potential for recovery, even though the outbreak may subside later (Ryan and others 1987; Seidel and Cochran 1981).

Industry has reported a serious reduction in the width of sapwood in defoliated larches, thereby making these trees less desirable or even unfit for utility poles. Casehardening, which prevents the penetration of preservatives into the wood, is another phenomenon reported by industry (Schmidt and others 1976).

Adverse weather conditions, such as the unusually low winter temperatures that significantly reduced larch casebearer populations in British Columbia in 1968-69, can help minimize this pest (Dawson 1971; Schmidt and Shearer 1990). High temperatures in Oregon were thought responsible for the death of some larch casebearer embryos before or at the time of hatching (Ryan 1985b). Food availability is another factor. *Hypodermella laricis* and *Meria laricis* may defoliate western larch, thereby reducing food supply for the moth, and resulting in starvation (Ferris 1995; Long 1988; Tunnock and Ryan 1985). A variety of native and introduced parasites and predators also help with larch casebearer control (Schmidt and Shearer 1990, 1995). Natural controls can help reduce the severity and extent of outbreaks, but they usually do not prevent them (Ferris 1995).

At least 50 species of parasites are known to attack the casebearer in eastern states but fewer to date have been found in the West. In the Idaho area infested by casebearer in 1957, three species of native parasites were recovered one year later (Denton 1972). In 1968, however, 16 native parasites were recovered (Denton 1972). These 16 species parasitized 17 percent of the casebearer population in that area. Similar surveys in British Columbia recorded nine parasitic species in the 1966 to 1968 period with a corresponding maximum parasitism of 14 percent of the casebearer (Andrews and Geistlinger 1969). In a 1970 survey in Montana, northern Idaho, and northeastern Washington, Bousfield and Lood (1973) recovered 20 species of parasites of casebearer. And in 1973, 29 parasites were found the West Kootenay area of British Columbia with a maximum of 18 percent parasitism (Miller and Finlayson 1974, 1977b). Undoubtedly, the number of native parasite species attacking casebearer will continue to increase. Of the native parasites, *Spilochalcis albifrons* (Walsh) and *Dicladocerus* spp. are the most common (Bousfield and Lood 1973; Denton 1972; Miller and Finlayson 1974).

Though native parasites will attack larch casebearers, they are minor factors in controlling populations. However, two introduced species, *Agathis pumila* and

Chrysocharis laricinellae, have substantially reduced the populations of the moth (Tunnock and Ryan 1985).

A. pumila, a host-specific, European parasite of larch casebearer, was credited with helping to check and control casebearer in the tamarack forests of eastern United States and Canada. As a result, it was selected as the primary parasite to release in western larch forests in 1960. That year, several thousand *A. pumila* adults were successfully introduced from New England into severely infested larch stands in northern Idaho. The spread rate of *A. pumila* from the release sites was slow. Although after 10 years it was recovered up to six miles (9.7 km) from the release point, the amount of parasitism decreased abruptly after 0.5 mile (0.8 km). This slow rate of spread was attributed to the tremendous casebearer host populations immediately available (Denton 1972).

To increase the rate of spread of *A. pumila* throughout the range of casebearer, 10,000 *A. pumila* adults in 1964, and 30,000 adults in 1965 were distributed in several hundred western larch stands throughout the casebearer infestation. Since then, greater establishment of *A. pumila* has been achieved by introducing this parasite while it is in its overwintering stage as larvae inside the casebearer (Denton and Tunnock 1968).

While most of the biological control efforts have centered on *A. pumila,* two other parasites of European origin, *Chrysocharis laricinellae* and *Dicladocerus westwoodii* Westwood, were released in Idaho and Washington in 1972 (Ryan and Denton 1973). In 1973 and 1974, additional *C. laricinellae* were released, and four new parasitoid species were released in 1974 (Ryan and others 1975). *C. laricinellae, D. westwoodii, D. japonicus, Elachertus argissa, Necremnus metalarus,* and *A. pumila* were released in 1975 and 1976 in Idaho, Montana, Oregon, and Washington (Ryan and others 1977). And from 1977 through 1980, additional parasites were released at eight sites in Idaho, Oregon, and Washington. Species released were *Diadegma laricinellum, Dicladocerus westwoodii, D. japonicus, C. laricinellae, E. argissa, N. metalarus,* and *A. pumila* (Ryan 1981). Ryan and others (1987) summarized releases of larch casebearer parasites throughout the west.

Both *A. pumila* and *C. laricinellae* introductions appear to have been successful in reducing larch casebearer populations and sustaining populations of the parasitoids (Ebel and others 1982; Hayes and Ragenovich 2001; Ismail and Long 1982). In the 10 years after its first release, records at five release sites showed substantial increases in *A. pumila* parasitism at some and little at others (Denton 1972). Up to 66 percent parasitism was found at one site, 40 to 50 percent at two sites, and two percent or less at the others. The highest rate of parasitism prompted a ten-fold decrease in casebearer numbers during the 10-year period (Denton 1972).

Flavell (1979) concluded that C. *laricinellae* was the "primary parasitoid in western populations." Surveys in the Boise and Payette National Forests indicated that C. *laricinellae* had established, but A. *pumila* was found at only two locations (Their 1982). And from 1973 through 1983, A. *pumila* and C. *laricinellae* appeared to impact populations of larch casebearer (Ryan 1985c). A. *pumila*-caused larvae mortality appeared to be holding larch casebearer populations at low densities by 1990 (Ryan 1990). However, in 1997 Ryan reported that "it is difficult to say that C. *laricinellae* adds substantially to the biological control that would have been achieved by A. *pumila* alone," and "In general, C. *laricinellae* is certainly less reliable than A. *pumila*."

No direct mortality from larch casebearer has been reported since the 1960s and neither have casebearer larval densities larger than 1.7 per spurshoot. Control mechanisms undoubtedly had some effect, but it is also possible that, since individual trees vary in their degree of susceptibility to larch casebearer, the most vulnerable individuals were killed early in the epidemic (Long 1988). In the late 1990s evidence of increasing populations in eastern Oregon was reported, so continued monitoring of this exotic pest is warranted (Hayes and

Ragenovich 2001). Long and Theroux (1979) presented a plan for monitoring larch casebearer densities.

Direct control of the casebearer is possible with aerial sprays of dimethoate, phosphamidon, or malathion (Denton 1966; Denton and Tunnock 1968). But direct control alone can provide only limited and local benefits, which may have little effect upon the total casebearer epidemic (Ferris 1995; Knapp 1983).

Aerial application of acephate in the fall has been effective in preventing heavy defoliation the following spring. Though it did not appear to negatively impact native parasitoids, treatment where *A. pumila, C. laricinellae,* and other introduced parasites occur, is not recommended until further study (Hard and others 1979). May spraying with phosphamidon, dimethoate, or malathion controlled larch casebearer well, and September spraying of malathion was also successful (Intermountain Forest and Range Experiment Station 1963a). Mexacarbate, malathion, fenitrothion, pyrethrins, Matacil, and tetrachlorvinphos were all toxic to larch casebearer larvae in laboratory tests (Lyon and May 1970). Malathion or Methoxychlor may be effective for small scale applications, but is not feasible on a forest-wide basis (Knapp 1983). Acephate and malathion were significantly less effective on fourth-instar larvae of larch casebearer than on parasites *C. laricenellae* and *Dicladocerus nearcticus*. Larch casebearer was less tolerant than the parasites to diflubenzuron (Page and others 1982).

The effect of predation on larch casebearer is largely unknown, but appears to include pentatomids, fomicids, vespids, spiders, and birds (Denton 1972; Tunnock and Ryan 1985). Black-capped chickadees, *Parus atricapillus*, appear to feed heavily on casebearer larvae.

Additional information about the ecology, effects, and control of larch casebearer is available (Dawson 1971; Denton and Theroux 1979; Ferris 1995; Ross 1976; Stark and others 1978; Tunnock and Ryan 1985)

Western spruce budworm

Another insect that sometimes jeopardizes western larch is the western spruce budworm (*Choristoneura occidentalis*), which reduces juvenile height growth and detracts from form (Fellin and Schmidt 1967; Schmidt and Fellin 1970). The usual diet of western spruce budworm larvae is the current year's foliage of many conifers (Fellin and Shearer 1968). Western spruce budworm primarly attacks Douglas-fir, grand fir, subalpine fir, and Engelmann spruce, but western larch, ponderosa pine, and western hemlock are also susceptible (Johnson and Denton 1975; Seidel and Cochran 1981). Western larch is a minor host of western spruce budworm in pure and mixed stands (Torgersesn 2001). Johnson and Denton (1975) discuss the ecology, effects, history, and management of western spruce budworm.

Western spruce budworm epidemics typically last from a few to 20 years (Seidel and Cochran 1981). The first reported outbreak of western spruce budworm was in 1922. In the 1960s the insect was found causing damage to cones, seeds, and stems of young western larch (Johnson and Denton 1975). Since 1962 budworm larvae have been found feeding not only on the foliage of larch seedlings, saplings, and poles but also severing the stems of the current-year terminal and lateral shoots, as well as damaging cones and seeds (Dewey and Jenkins 1982; Fellin and Shearer 1968; Johnson and Denton 1975). This is occurring wherever the distributions of larch and budworm overlap (Schmidt and Shearer 1990).

Western spruce budworm dispersal did not appear to be influenced by stand structure in previously harvested stands of western Montana (Carlson and others 1988). Survival of western spruce budworm was lower on western larch (49 percent) than on Douglas-fir, subalpine fir, and Engelmann spruce (82-88 percent) in north-central Washington (Beckwith 1983).

Of the injuries described, the most serious is severance of the current-year terminal shoots (Schmidt and Fellin 1973; Schmidt and Shearer 1990), resulting in height growth losses of 25 to 30 percent (Schmidt and Shearer 1990).

Repeated severing of stems and upper laterals produces crooked boles and misshapen, bush-like trees (Fellin and Schmidt 1973a). In response to loss on the terminal, lateral branches turn up to replace the leader and a fork is formed. Although forks do not appear to persist more than about five years, crooked boles remain to document the previous damage.

A two-year field study found that western spruce budworm rarely severe leaders and lateral shoots of western larch saplings. However, no egg masses were found on sapling-sized western larch (Wissenbach 1984). Net annual height growth of trees whose terminals were severed averaged 27 percent less than that of trees whose terminals were not severed. Greater height losses might have been expected, but some growth was usually regained when one or more laterals turned up and replaced the severed terminal. Because about 25 to 75 percent of the tree terminals in the study area were severed annually during a 10-year period, the overall damage added up to a substantial loss in height growth for the stand.

Western larch management can be adversely influenced by sustained budworm damage. Persisent high budworm populations in the Northern Rockies increase the incidence of multiple-topped trees, and trees become less able to outgrow forks. Moreover, severance of terminal leaders places larch at a competitive disadvantage with some of its associated species, particularly lodgepole pine, and thus reduces its potential for later recovery. Defoliation of healthy young host trees is generally light, so height growth is not significantly impacted (Carlson and others 1988).

Schmidt and Fellin (1973) speculate budworm may infest western larch forests on a wide range of site qualities and ecological habitat types. They expect significant but less pronounced effects of budworm on the better sites. Although the incidence of budworm damage did not appear related to stand density in their study, they indicated that thinning has the potential of ameliorating the effects of budworm damage by establishing a more vigorous stand. Not only are the more vigorous trees with large-diameter shoots severed less often than those with small-diameter shoots, but the trees are better able to recuperate rapidly when budworm populations decline. Carlson and Wulf (1989) recommend rating stands for susceptibility to the western spruce budworm and planning treatments accordingly. Recommended silvicultural practices include the following:

- Encourage species diversity by favoring seral trees and selecting against shade-tolerant hosts.
- Use thinning and release to regulate stand density and maintain vigor and growth
- Use even-aged regeneration systems with periodic thinnings
- Remove overstory trees after regeneration is established in seed-tree and shelterwood systems
- Remove unhealthy trees
- Remove heavily defoliated trees; keep trees that have light or no defoliation to encourage phenotypic or genetic resistance.
- Regenerate host stands to less susceptible species prior to maturity
- Create seral stands in homogenous areas of late successional host stands

In young western larch stands in Montana, several fertilizer treatments, especially those that contained nitrogen, increased all types of budworm feeding. Increased growth due to fertilizers may be offset by increased budworm feeding, and until further study, fertilization should be delayed until budworm populations decrease (Schmidt and Fellin 1983).

Although we usually associate unseasonal frosts and low temperatures with tree damage, these factors can have a negative effect on budworm and, therefore, a positive effect on the trees. Temperature as low as 21° Fahrenheit (-6° C) was recorded in western Montana in mid-June 1969, the period when western budworm larvae are actively feeding. Fellin and Schmidt (1973b) found that the freeze reduced budworm populations on western larch, Douglas-fir, and ponderosa pine more than 90 percent, and subsequent budworm damage to young western larch up to 70 percent the following season.

Densities of dispersing larvae did not affect growth and development of even-aged conifer stands in western Montana, most likely a result of heavy predation on the pest that occurs in young stands (Carlson and others 1988). Predation on western spruce budworm by ants and birds can reduce injury on small Douglas-fir and western larch trees by up to 50 percent (Carlson and others 1984). Another study in Montana found that ants reduced larval survival and pupal populations on western larch. Birds apparently removed some larvae and pupae, but had little overall effect. Increased ant densities may help control western spruce budworm on western larch and Douglas-fir seedlings (Campbell and others 1984).

Larch sawfly

The larch sawfly (*Pristiphora erichsonii*) is among the most destructive defoliators of larch species in North America. Its needle-feeding habit may reduce growth and cause mortality (Drooz 1960). The species also attacks tamarack, but has not been reported on alpine larch (Drooz 1956). Western larch is more resistant to larch sawfly attack than Japanese larch and European larch (Genys and Harman 1976). Drooz (1956, 1960) discussed the ecology, effects, and management of larch sawfly.

Larch sawflies begin by feeding on the edges of needles, which turn brown. Later they eat entire needles. When populations are high, trees may be entirely defoliated, resulting in reduced growth. Repeated defoliation has killed tamarack in eastern North America, but not in British Columbia (Erickson 1984; Erickson and Ross 1977).

The first report of larch sawfly in North America was on European larch at the Arnold Arboretum near Boston, Massachussetts, in 1880. Over the next 30 years, outbreaks in tamarack occurred as far west as Minnesota and Alberta. In British Columbia, the first record was made in 1930, and in 1935, it was found on western larch on the Flathead National Forest in northwestern Montana (Coppel and Leius 1955; Drooz 1956, 1960; Erickson 1984; Erickson and Ross 1977). By 1942, it was present throughout western larch's range (Drooz 1960; Narin and others 1962). Larch sawfly epidemics on western larch in British Columbia occurred in the 1940s and again in 1964. From 1965 through 1967, 320,000 to 370,000 acres (130,000-150,000 ha) of western larch were defoliated annually in southeastern British Columbia (Erickson 1984; Erickson and Ross 1977).

Insects of the orders Hemiptera, Nruroptera, Coleptera, and Hymenoptera are known predators of the larch sawfly (Drooz 1960). Other predators include spiders, rodents, and birds. Fungal and bacterial diseases can affect population levels, as can climate, availability of oviposition sites, and availability of food (Drooz 1960; Erickson 1984; Erickson and Ross 1977). The orb spider has been observed feeding on larvae, and mites of the genus *Balaustrum* have attacked larvae in Canada. Several spider species and a mite have been recorded feeding on adult sawflies in Minnesota. Nematode control of western larch sawfly may be effective. Fish, frogs, rodents, and birds have also been seen feeding on larch sawflies (Drooz 1960). Forty-three bird species that prey on the larch sawfly were found in tamarack bogs. Birds may affect sawfly populations, especially at low densities, and many species prefer adult sawflies (Buckner and Turnock 1965).

A parasitic wasp, *Mesoleius tenthredinis,* was introduced into British Columbia in 1934, and has spread throughout western larch's range in the province. *M. tenthredinis* and *Tritneptis klugii* are the two most important parasites of larch sawfly in British Columbia (Forest Entomology Committee 1946). Insecticides appropriate for conifer defoliators may be used on ornamentals (Erickson 1984; Erickson and Ross 1977).

Other defoliators

Other defoliators that affect western larch include the two-lined sawfly (*Anoplonyx laricivorus*), larch shoot moth (*Argyresthia laricella*), gypsy moth (*Lymantria dispar*), western hemlock looper (*Lambdina fiscellaria lugubrosa*), gray spruce looper (*Semiothisa sexmaculata*), false hemlock looper (*Nepytia canosaria*), black army cutworm (Actebia fennica), and spruce spider mite (*Oligonychus ununguis*).

The black army cutworm (*Actebia fennica*) can cause damage to western larch from larval feeding, which begins early spring and continues until pupation occurs in mid-June. Though larvae generally prefer succulent herbaceous plants, western larch seedlings have been defoliated when plenty of herbaceous vegetation was available, indicating high palatability of western larch to the cutworm larvae (Maher 1990). Growth losses were highest in the year of defoliation, and western larch seedlings in recently planted stands of British Columbia had highest mortality when defoliation occurred one year after planting (Maher 1990; Maher and Shepherd 1992).

Terminal damage, which reduces height growth rate, affected pine and western larch more then Douglas-fir or spruce. However, seedlings that did not incur terminal damage recovered from defoliations with little loss of height growth. After defoliation by the black army cutworm, mortality of western larch planted seedlings from defoliation was greater than that from poor planting. Overall, western larch suffered less than Douglas-fir, lodgepole pine, and Engelmann spruce from defoliation by black army cutworm (Maher and Shepherd 1992).

Monitoring of susceptible biogeoclimatic subzones is recommended. In high risk areas, planting after the onset of pupation is recommended, and survival should be monitored the following year, with additional plantings as necessary. Insecticide treatment may also be effective (Maher 1990).

For many species of *Adelges,* larch species are secondary hosts. *A. oregonensis* commonly feeds on western larch twigs and needles. In summer, tufts of white wool can be seen on foliage and bark. In winter, they appear as small black nymphs. Adelgids can cause yellow spotting, distortion, and in severe infestations, dropping of needles (Duncan 1996).

The larch shoot moth, *Argyresthia laricella,* occurs on western larch as well as tamarack and European larch. In early summer, eggs are laid at shoot bases.

Larvae then feed within the shoots and pupate in the spring. Moths appear several weeks later. Though the larch shoot moth kills the aerial portion of shoots, its effects are not considered economically important. Several parasites of the moth have been reared (Eidt and Sippell 1961).

The gray spruce looper (*Semiothisa sexmaculata*) is a defoliator that occurs on western larch, with occasional severe infestations (Stewart 1994). Though western hemlock is the primary host of western hemlock looper, during outbreaks western larch may also be defoliated. Larvae begin feeding on old and new western larch needles by mid-July, often chewing needles off at the base. Partially chewed needles typically dessicate, turn brown, and drop. Entire trees may be defoliated during severe infestations. Typically, feeding begins in the upper crown, and as feeding progresses, the risk of top kill and tree death increases (Koot 1994).

Management recommendations for this insect are not currently available, though synthetic pheromone treatment is under development. Naturally occurring diseases of the looper are thought to have been largely responsible for the decline of an outbreak in British Columbia and may be important in the future (Stewart 1994).

Spruce spider mite (*Oligonychus ununguis*) is considered an important pest of forest and ornamental conifers. Larch species are among the preferred hosts, though damage is not usually severe. These arachnids suck sap from needles, causing needle discoloration and, in heavy infestations, needle drop. Most damage in larch trees occurs in the lower crowns, and mortality is common in seedlings and small trees and may even occur in large areas of mature trees (Marshall 1986).

The genus *Zeiraphera* was first recorded on western larch in British Columbia in 1965. These insects tie needle bundles into tubes then feed on the terminal portion of the needle surfaces within the tubes. When tubes break, partially eaten needles are exposed, resulting in a yellowish-brown appearance of infected stands, similar to *Hypodermella laricis*. Later, affected needles drop (Geistlinger and Ross 1966).

A short-lived, epidemic infestation of larch needleworm, *Z. improbana,* was reported in the Nelson Forest District in southern British Columbia (Lindquist 1973; Molnar and others 1965), and the larch budmoth (Z. *griseana*) has caused heavy but sporadic damage to western larch (Schmidt and others 1976).

Wood and Bark insects

Douglas-fir beetle

Bark beetles (*Dendroctonus* spp.) are not generally a serious threat to western larch, which is a secondary host (McMullen 1977), but the gallery system in inner bark can eventually girdle tree and may cause death (Humphreys 1995; McMullen 1977).

The Douglas-fir beetle (*Dendroctonus pseudotsugae*) occasionally attacks felled, injured, or weakened trees and it has been known to kill apparently healthy, mature trees (Humphreys 1995; Keen 1952; McMullen 1977; Reed and others 1986). Several months to a year after attack, depending on weather, foliage becomes discolored (Humphreys 1995; McMullen 1977). Larvae prefer western larch over eight inches (20 cm) d.b.h. and will attack smaller trees, but brood production is lower (Humphreys 1995; McMullen 1977). McMullen (1977) discusses bark beetle ecology, effects, and control.

Hybrid *Dendroctonus* were not as successful in western larch as in Douglas-fir (Furniss and Tovar 1980). Two blue-stain fungi, *Ophiostoma* *pseudotsugae* and *Leptographium abietinum*, which are associated with the Douglas-fir beetle, are not able to survive in western larch, which may explain why Douglas-fir beetle broods repeatedly fail in western larch (Neal and Ross 1999).

Humphreys (1995) describes the ecology, effects, and management of the Douglas-fir beetle. High concentrations of 3-carene in western larch apparently deter attack by Douglas-fir bark beetles (Reed and others 1986). Perhaps in felled trees 3-carene concentrations decrease with time, allowing bark beetles to attack (Reed and others 1986).

Because Douglas-fir beetles prefer felled trees, removing logs and treating slash after cutting can help minimize Douglas-fir beetle infestations of western larch (Humphreys 1995; McMullen 1977). Remedial measures include felling groups of trees to attract beetles, then removing infested material (McMullen 1977), as well as pheromone baiting (Humphreys 1995). Selective placement of multiple-funnel traps baited with strong aggregation pheromone lures to attract beetles, followed by removal of trapped beetles, may reduce effects of infestation (Ross and Daterman 1997). Burning may effectively destroy broods (Humphreys 1995).

Other wood and bark insects

Ross (1967b) lists, with emergence dates, species of wood- and bark-feeding Colepterans that were reared from western larch logs in 1928-29 and 1965-66. western larch borer (*Tetropium velutinum*), *Serropalpus substriatus*, flatheaded fir borer (*Melanophila drummondi*), and Douglas-fir beetles were common. Six engraver beetles including, *Scolytus subscaber* and *S. sobrinus* attack western larch in British Columbia (Woods 1973). Other engraver beetles that cause infrequent damage are the engraver beetle (*Ips acuminatus*) and the larch engraver (*Scolytus laricis*) (Schmidt and others 1976).

Western larch is considered unfavorable to termites, *Reticulitermes flaipes*. However, in a force-feeding test on heartwood blocks of 11 unfavorable coniferous genera, termite survival was better on Douglas-fir, subalpine fir, and western larch test material (sawdust, solvent-extracted sawdust, and wood extracts on filter paper) than that of western hemlock and Engelmann spruce (Carter and Smythe 1974). *R. flavipes* preferred decayed wood, including that of western larch, over sound wood. Survival was moderate on western larch compared to other species tested (Smythe and others 1971).

The western larch borer, *Tetropium velutinum*, bores L-shaped galleries in western larch sapwood 1.0 to 1.9 inches (25 to 47 mm) deep and 1.1 to 2.7 inches

(28-69 mm) long. Eggs are laid from May through August, and larval sapwood penetration begins about six weeks afterward (Ross 1967a). Vanderwal and Ross (1968) reported that the borer preferred western larch logs that were felled in May and June, and was able to penetrate deeper into May-felled than winter-felled logs. Prompt removal or utilization of felled trees is recommended for control of western larch borer (Ross 1967a). Lindane applied in June may also protect freshly felled trees (Ross and Geistlinger 1968).

Cone and Seed insects

Anthomyiid larvae, western spruce budworm, *Adelges viridis,* and *Resseliella* spp. contributed to decreased cone or seed production at 13 sites in Montana, Idaho, Oregon, and Washington. Acephate implants were being investigated for cone maggot and western spruce budworm control with poor results (Jenkins and Shearer 1989). Damage to cones in Idaho and Montana was caused by a midge, a cone maggot, a coneworm, and the western spruce budworm (Dewey and Jenkins 1982). Though the fir coneworm (*Dioryctria abietivorella*)is found only occasionally on western larch, it may completely destroy cones in years of light cone crops (Hedlin and others 1980). Western larch is a host of the cone cochylid (*Henricus fuscodorsana*), whose larvae feed in cones, causing damage to scales and seeds. This pest may decrease seed crop by as much as 10 percent (Hedlin and others 1980). In British Columbia, seed and cone insects typically cause light losses in western larch (Miller and Ruth 1989).

3. Animals

Bears (*Ursus* spp.) may girdle and kill vigorous young western larch saplings and small poles by stripping the bark on the lower bole, sometimes to a height of six feet (2 m), in search of the sugars that are concentrated in the sap layer in late spring (Cook 1969; Fowells 1965; Schmidt and Gourley 1992; Schmidt and Shearer 1990, 1995; Schmidt and others 1976; Shearer and Halvorson 1967). Although this damage is not considered a major problem throughout its natural range, some larch stands sustain significant mortality causing a significant change in species composition (Shearer 1990). Even when damaged trees survive, the wound often serves as an entry point for diseases that cause major defects or breakage later in the life of the trees (Schmidt and Gourley 1992).

Though bears generally favor Douglas-fir in western forests of Oregon and Washington, in western Montana and the Northern Rockies, bears prefer western larch for feeding (Schmidt and Gourley 1992). Up to five percent of pole-size larches have been damaged by bears in a given year at Coram Experimental

Forest in Montana. Most damage occurered when trees were 24 to 34 years old, and more dense stands always had less damage (Schmidt and Gourley 1992). In three sample areas of the Kootenai Nataional Forest, 63 percent of the bear-damaged trees were western larch. Bark stripping damage was over five times greater in thinned study areas than in adjacent unthinned ones. Damaged trees were four to 13 inches d.b.h. and 85 percent were between four and eight inches (Mason and Adams 1989). Stands with root rot and those fertilized with urea appear to attract bears (Schmidt and Gourley 1992).

Deer mice, red-tailed chipmunks, red backed voles, and long tailed voles accounted for 96 percent of the animals caught over five years on a clearcut, broadcast burned area of western larch forest type (Halvorson 1982). Moderate to heavy rodent populations usually do little damage to larch seed or seedlings (Shearer and Halvorson 1967), though their seed-eating habits can affect the establishment of seedlings (Schmidt and Shearer 1990).

Douglas-fir seed was selectively taken in preference to larch and spruce from fall-sown seed spots at Coram. In one instance, all seed spots sown with Douglas-fir seed were disturbed and 38 percent of the seed was found hulled. An undetermined additional amount may have been carried off the plots and not accounted for. In comparison, 40 and 13 percent of western larch and spruce seed spots, respectively, were disturbed, with at least three and one percent, respectively, of the seed destroyed. Spring-sown western larch and Douglas-fir seed sustained only 60 and 15 percent as much loss as fall-sown seed (Shearer and Halvorson 1967).

American red squirrels (*Tamiasciurus hudsonicus*) commonly cut and cache western larch cones, particularly in years when a plentiful cone crop of western larch coincides with sparse cone crops of associated species. In the process of cutting cones, squirrels occasionally clip small branches, thereby reducing lateral growth and possibly the number of the buds that may develop into cones the next year. Along with deer mice, they can be problematic in low seed production years (Cook 1969; Fowells 1965; Schmidt and Shearer 1976, 1995; Shearer and Halvorson 1967; Stillinger 1944).

Some birds also reduce germination capacity by foraging heavily on seeds. Schmidt and others 1976,Shearer and Halvorson 1967). Porcupines (*Erethizon dorsatum*) are common in the western larch type and cause heavy damage to tamarack in the eastern United States, but they seldom damage western larch (Cook 1969; Fowells 1965). Though deer, elk, and moose occasionally browse larch, only minimal damage has been reported (Cook 1969; Fowells 1965;

Gaffney 1941). See Chapter Four for more information about animals' use of western larch for food and cover.

CHAPTER TWO

ECOLOGY OF WESTERN LARCH FORESTS

In eastern Oregon, northern Idaho, and western Montana, the western larch ecosystem occurs in the mountains, generally over 3,000 feet (900 m) with less than 20 percent gently sloping. Western larch typically comprises at least 50 percent of the type, but western white pine may occupy up to 20 percent (Garrison and others 1977). Koch (1945) eloquently describes a western larch forest on the west side of Seeley Lake, Montana:

> ...this tract of several hundred acres is as unique and as beautiful in its own way as the better known redwoods or the sugar pines of the Sierra.... It is not a dark, close forest, but an open, park-like, sunny stand with the big cinnamon colored tree columns rising from a low ground cover of kinnikinnick [bearberry] and pine grass. Some portions of the area have an understory of lodgepole pine, Douglasfir [sic], and alpine fir [subalpine fir], but the most striking and characteristic parts of the stand are composed of pure larch from four to seven feet in diameter.
>
> Since the larch is a deciduous tree, this forest has a variable charm which is lacking in most coniferous stands. In the early spring the vivid fresh green of the new larch needles contrasts pleasingly with the darker green of Douglas-firs and lodgepole

> pines, and the forest floor blossoms out with masses of the striking glacier lily, *erythroniumI* [sic], which curiously is a creamy white in this locality, rather than the usual bright yellow.
>
> In October, when the larch foliage has turned to a clear golden yellow, and the ground is carpeted with gold from the fallen needles, this forest is breathtakingly beautiful.

A. DISTRIBUTION

With few exceptions, western larch occurs naturally west of the Continental Divide in the Columbia River drainage (Schmidt and Shearer 1995). The species occurs from southeastern British Columbia and occasionally in extreme southwestern Alberta southward into Washington and northern Oregon east of the Cascades, western Montana, and northern and west-central Idaho (Arno 1985; Brunton 1984; Conner and O'Brien 1995; Daubenmire and Daubenmire 1968; Dorn 1988; Eyre 1980; Fiedler 1995; Fowells 1965; Hosie 1969; Knudsen and others 1968; Lloyd and Vyse 1995; SAF 1954; Schmidt and Shearer 1990; Seidel and Cochran 1981; Sudworth 1908).

In Idaho, western larch's southern limit is 44°15', and in the Blue Mountains of Oregon, it extends slightly further south (Steele and Geier-Hayes 1995). It occurs in the central and northeastern part of Washington and west of the Continental Divide in Montana, from the Salmon River Mountains northward (Conner and O'Brien 1995). Only one source reports that its range extends into Colorado (Hitchcock and Cronquist 1973).

Western larch's range in British Columbia is limited to the southern interior portion (Whitford and Craig 1918), but it occurs in four of 12 biogeoclimatic zones in British Columbia and many habitat types from the valleys to high elevations (Lloyd and Vyse 1995). The species is found only in the southeastern part of the Douglas-fir zone, and it is frequently associated with previously burned areas (Hope and others 1991a). Its occurrence in Alberta, including Kananaskis Provincial Park, the Kananaskis Valley, Crowsnest Pass, and the Bow Valley, is most likely a result of seed dispersal through mountain passes from British Columbia (Brunton 1984).

Local distribution of western larch is strongly related to past occurrence of fires (Steele and others 1981). See Chapter Three for more information about western larch's relationship to fire.

Western larch is occasionally planted or seeded outside its natural range in the United States and Canada (Brunton 1984; Cole 1993; Lloyd and Vyse 1995), and it has been established in at least one planting in Salt Lake County, Utah (Welsh and others 1987). In these areas, it typically grows faster than native species (Lloyd and Vyse 1995).

The U.S. Forest Service developed a National Hierarchical Framework of Ecological Units. For each unit in the northern region, Nesser and others (1997) describe subsections, which differ from adjacent units in geologic materials, geomorphic features, and climate. Ecological units of the northern region of the U.S. where western larch may occur are as follows (Nesser and others 1997):

331A	Palouse Prairie
331D	Northwestern Glaciated Plains
M332A	Idaho Batholith
M332B	Bitterroot Valley
M332D	Belt Mountains
M333A	Okanogan Highlands
M333C	Northern Rockies
M333D	Bitterroot Mountains

Bureau of Land Management physiographic regions (Bernard and Brown 1977) where western larch occurs are as follows:

Region 2	Cascade Mountains
Region 5	Columbia Plateau
Region 8	Northern Rocky Mountains

B. VEGETATION TYPES

1. Associated Vegetation

Except when it is young, western larch is rarely found in pure stands. Its most common tree associate is Douglas-fir, which gradually replaces western larch along the eastern limits of the western larch's range (SAF 1954; Shearer 1980a). On low-elevation, dry sites it is found with ponderosa pine and ponderosa pine's importance increases with increasing dryness (Shearer 1980a). Common associates in warm, moist forests include grand fir, western hemlock, western redcedar, and western white pine. In cool, moist, subalpine forest types, Engelmann spruce, subalpine fir, lodgepole pine, and mountain hemlock are more common. Hardwoods that frequently occur with western larch include paper birch, balsam poplar, and quaking aspen. (Boe 1958; Hosie 1969; SAF 1954; Schmidt and Shearer 1990, 1995; Shearer 1980a; Shearer and Kempf 1999; Whitford and Craig 1918).

Western larch forests typically have rich understories of herbaceous and shrub layers (Pfister and others 1977). Major understory associates include beargrass, huckleberry, thimbleberry, menziesia, ninebark, Saskatoon serviceberry, Oregon boxwood, and bearberry (Boe 1958; Hosie 1969; SAF 1954; Schmidt and Shearer 1990, 1995; Shearer 1980a; Shearer and Kempf 1999). Understory density and species composition vary with habitat (Schmidt and Shearer 1990).

On 20 study areas totaling 100 acres (40 ha) on the Coram Experimental forest, nine conifer, 21 shrub, and 58 herbaceous species were noted (Schmidt

1980a). Shrubs included species of *Acer, Alnus, Amelanchier, Physocarpus, Rubus, Symphoricarpos, Vaccinium,* and *Salix.* Herb species were from the genera *Aralia, Arnica, Calamagrostis, Clintonia, Epilobium, Linnaea, Xerophyllum,* and others (Schmidt and Shearer 1990).

In western Montana, Idaho, eastern Oregon, and Washington, the ponderosa pine-western larch-Douglas-fir type occupies intermediate zones between ponderosa pine and the moister western larch-Douglas-fir sites. Grand fir, western white pine, and lodgepole pine may also be present in minor amounts. Characteristic shrubs are ninebark, Saskatoon serviceberry, and bearberry (Boe 1958).

The grand fir-western larch-Douglas-fir combination occurs along the east slopes of the Cascade Range, the Okanogan highlands in northern Washington, and in Idaho, Montana, and the northern Blue Mountains of Oregon. Associates are usually western hemlock, western white pine, Engelmann spruce, and ponderosa pine. Boxwood occurs in this type, as well as dwarf Oregon-grape and ninebark (Boe 1958).

2. Habitat types

Western larch is not considered a climax species, but it is a long-lived early-succession species in Douglas-fir, Engelmann spruce, grand fir, lodgepole pine, mountain hemlock, western hemlock, western redcedar, and subalpine fir habitat types (Alexander 1988; Boe 1958; Daubenmire and Daubenmire 1968; Driscoll and others 1984; Ferguson and Byrne 2000; Franklin and Mitchell 1967; Garrison and others 1977; Habeck 1967a, 1967b; Johnson and others 1994; Ketcheson and others 1991; Martin and others 1979; Mueggler 1965; Pfister 1972; Schmidt and Shearer 1995; Wellner 1970). It is is a common seral species in the spruce-fir zone and is often a major post-disturbance component of mountain hemlock communities, especially below 5,600 feet (1,700 m) elevation (Habeck 1967a). It is also an important species in the pacific silver fir zone of the Cascade Mountains (Emmingham and Halverson 1982).

Western larch is a minor associate of subalpine fir in three of eight provinces in the Cascade Range in Washington (Franklin and Mitchell 1967). In the eastern Washington Cascade Range, it is a major seral species in the Douglas-fir and grand fir zones and a minor seral species in the western hemlock and subalpine fir zones (Franklin and Dyrness 1973; Seidel and Cochran 1981). In southwestern Washington, western larch occurs in the ponderosa pine, Douglas-fir, true fir, and subalpine fir zones (Clarke and Bryce 1997).

In the central Oregon Cascade Range, western larch is a minor seral species in the Douglas-fir and grand fir zones, and in the Ochoco and Blue mountains, it is a major seral species in the grand fir zone (Franklin and Dyrness 1973; Seidel and Cochran 1981). Western larch occurs in grand fir mosaic habitats occasionally in northern Idaho and is common in this type in northeastern Oregon (Ferguson and Byrne 2000). In northeastern Oregon, it is found in the ponderosa pine, Douglas-fir, true fir, and subalpine fir zones (Clarke and Bryce 1997; Pfister and others 1977).

Elzinga and Shearer (1997) describe western larch as a dominant canopy species in the western larch, Engelmann spruce-subalpine fir, and interior Douglas-fir forest types of northwestern Montana. Descriptions of several plots where western larch occurred are summarized in Table 9. It is also found in the grand fir and cedar-hemlock zones of Montana (Schweitzer and others 1975). It is a minor component of subalpine forest communities in northwestern Montana (Habeck 1967a) and on the north-facing aspects of the subalpine fir-lodgepole pine-Engelmann spruce forest at Lubrecht Experimental Forest (Cooper and others 1991; Tesch 1981). In northern Idaho, western larch is a major seral species in the cedar-hemlock zone (Mueggler 1965).

Table 9: Comparison of old-growth stands in the Coram Research Natural area in northwestern Montana (All plots except plot 3 burned in 1890) (Elzinga and Shearer 1997)

Plot 1	**Old growth western larch cover type**
Canopy	35 m high; 200-300 year old western larch, 100-150 year old western white pine
Mid-canopy	100-150 year old spruce and lodgepole; 50-70 year old subalpine fir, western hemlock and western white pine
Habitat type	Subalpine fir-queencup beadlily h.t., wild sarsaparilla phase
Larch description	Largest trees (33-67 d.b.h.) and oldest (to 283) in canopy
Plot 2	**Old growth western larch cover type**
Canopy	150-300 year old western larch, 100 year old western white pine
Mid-canopy	Subalpine fir <70 years old, spruce 100-160 years old
Habitat type	Subalpine fir-queencup beadlily h.t., wild sarsaparilla phase
Larch description	Most ~200 years old, some > 300; all >30 cm d.b.h.
Plot 3	**Young stand western larch cover type**
Canopy	Western larch and Douglas-fir <100 years old are oldest trees
Mid-canopy	
Habitat type	Western hemlock-queencup beadlily-wild sarsaparilla h.t.
Larch description	70% of all trees, most abundant, none >18.4 cm d.b.h.
Plot 4	**Old-growth western larch cover type**
Canopy	30-35 m high; 200+ year old Douglas-fir, 300+ year old western larch, 150-200 year old western white pine, and 1-1--- year old lodgepole pine
Mid-canopy	100-year old spruce, subalpine fir, and western hemlock
Habitat type	Western hemlock-queencup beadlily h.t., wild sarsaparilla phase
Larch description	3 largest are 46-54 cm d.b.h.; 60% basal area with Douglas-fir, only in largest size classes
Plot 8	**Old growth western larch cover type**
Canopy	200 year old Douglas-fir, 250-300 year old larch
Mid-canopy	Subalpine fir, occasional Douglas-fir
Habitat type	Subalpine fir-queencup beadlily h.t., beargrass phase
Larch description	Smallest >20cm; 79% basal area with Douglas-fir; lack of regenerating western larch

Western larch occurs frequently as a post-fire seral species in the eastern portion of the montane spruce zone of British Columbia (Hope and others 1991b). In British Columbia, it is also found in the interior Douglas-fir, montane spruce, and southern interior cedar-hemlock zones (Brayshaw 1970; Hope and others 1991a; Ketcheson and others 1991; MacKinnon and others 1991; Vyse and DeLong 1994). Classifications that desribe plant communities in which western larch is an important seral species are summarized in Table 10.

Table 10: Classifications describing plant communities in which western larch is an important seral species

STATE	REFERENCES
Idaho	Cooper and others 1987, 1991; Daubenmire 1952, 1953; Hall and Hansen 1997; Steele and Geier-Hayes 1989, 1992, 1993, 1995; Steele and others 1981
Montana	Hansen and others 1988; Hansen and others 1995; Pfister and others 1972, 1977
Oregon	Franklin and Dyrness 1973; Hall 1973; Williams and Lillybridge 1983
Washington	Daubenmire 1952, 1953; Franklin and Dyrness 1973; Hall 1973
British Columbia	Brayshaw 1970

Forest cover types, classified according to existing forest cover, where larch occurs are (Eyre 1980, SAF 1954):

MAJOR COMPONENT:
206 Engelmann spruce-subalpine fir
210 Interior Douglas-fir
212 Western larch
213 Grand fir

214 Ponderosa pine-western larch-Douglas-fir

MINOR COMPONENT:
205 Mountain hemlock
215 Western white pine
218 Lodgepole pine
220 Rocky Mountain juniper
224 Western hemlock
226 Coastal true fir-hemlock
227 Western redcedar-western hemlock
228 Western redcedar
233 Oregon white oak
237 Interior ponderosa pine

Forest and Range Ecosystems (Garrison and others 1977) where western larch occurs include the following:

FRES20 Douglas-fir
FRES21 Ponderosa pine
FRES22 Western white pine
FRES23 Fir-spruce
FRES24 Hemlock-sitka spruce
FRES25 Larch
FRES26 Lodgepole pine

Kuchler habitat types (Kuchler 1964) in which western larch may occur include:

K004 Fir-hemlock forest
K010 Ponderosa shrub forest
K011 Western ponderosa forest
K012 Douglas-fir forest
K013 Cedar-hemlock-pine forest
K014 Grand fir-Douglas-fir forest
K015 Western spruce-fir forest

C. SUCCESSION

Western larch is the least shade tolerant conifer in its range (Arno and Gruell 1983; Fiedler 1995; Fiedler and Lloyd 1995; Fischer and Bradley 1987; Habeck 1968; Schmidt and Shearer 1995; Shearer 1990). As such, it is always a seral species whose populations have been historically maintained by disturbances such as wildfire and glacial retreats (Cattelino and others 1979; Daubenmire 1953, 1966; Fiedler 1995; Fiedler and Lloyd 1995; Schmidt and Shearer 1995; Schmidt and Larson 1989; Shearer 1980a, 1990) and is therefore usually found in even-aged stands (Schmidt and Shearer 1995). It is an aggressive pioneer species after fire or other major disturbance (Arno and Gruell 1983; Fiedler 1995; Habeck and Mutch 1973; Martin and others 1979) and competes best on moist sites (Fischer and Bradley 1987; Habeck and Mutch 1973). In drier environments where fires are frequent, western larch may form a "fire climax" (Turner 1985).

This aggressive pioneer quickly colonizes disturbed areas and grows rapidly (Fiedler 1995; Fiedler and Lloyd 1995; Schmidt and Shearer 1995; Shearer 1980a). Western larch seeds are short-lived but often survive fire in the canopy of mature trees, and they are extremely light allowing for long dispersal distances after disturbance (Cattelino and others 1979). Western larch uses nitrogen more efficiently than evergreen trees, reducing its dependence on soil for nitrogen and increasing its effectiveness as a pioneer in disturbed, low-nutrient habitats (Gower and others 1995; Tonn and others 1995).

Western larch must establish promptly following disturbance, before competition and shade inhibit germination and growth (Antos and Shearer 1980; Cattelino and others 1979; Tippets 1996). Insufficient sunlight or exposed mineral soil will delay establishment, allowing development of shrubs or more shade-tolerant tree species (Antos and Shearer 1980; Tippets 1996).

Typically, western larch develops in a mixed stand, the exact composition of which depends on site conditions and habitat type (Habeck 1967b). Under favorable conditions, western larch secures an early height advantage over its associates and continues to outgrow them for nearly a century unless weakened by insects or disease (Fiedler 1995; Fiedler and Lloyd 1995; Schmidt and Shearer 1995; Shearer 1980a). It is typical for old-growth forests (greater than 150 years) to have western larch and Douglas-fir dominated overstories 150 to 130 feet (35-40 m) tall, with understories of grand fir, subalpine fir, and Engelmann spruce (Antos and Habeck 1981). As stands mature and competition for light and soil moisture increases, western larch growth declines (Roe 1956). However, western larch's long lifespan and resistance to damage from fire and pathogens account for the presence of relict overstory trees in late-successional stands that can repopulate burned stands after fire or other disturbance opens the canopy and removes competition (Fiedler and Lloyd 1995; Habeck 1967a, 1967b, 1968; Shearer 1990).

Habeck (1968) found that western larch often present in climax communities of cedar-hemlock associations in Glacier National Park. In addition, most dead snags and windfallen trees in older communities were western larch. In pioneer communities, western larch was closely associated with lodgepole pine. Though it was a minor component in lodgepole pine-dominated stands after a single burn, repeated burning during the early stages of succession greatly increased the proportion of western larch on those sites. He concluded that the large number of mature western larch trees in late-development stands were probably a result of former multiple burns in those areas. Western larch species importance values within Habeck's six successional gradient segments, where "I" represents stands less than 50 years of age and "VI" represents stands approximately 400 years old, are as shown in Table 11.

Without fire or other stand-replacing disturbance, shade tolerant associates such as Douglas-fir, grand fir, or subalpine fir form understories that quickly shade out western larch seedlings and begin to replace western larch (Larsen 1929; Roe 1956; Schmidt and Shearer 1995; Shearer 1990). A study of general land office records for western Montana indicated that due to reduced fire frequency in the Fort Missoula Timber Reserve, Douglas-fir has increased in stand dominance compared to western larch and ponderosa pine (Habeck 1994). In late successional cedar-hemlock forests in northern Idaho, Moeur (1992) found very few western larch or other shade intolerant trees. She predicted that western larch will be "excluded from these sites in the absence of a stand-replacing disturbance". Likewise, in Washington's Swauk Late Successional Reserve in Wenatchee National Forest, Camp (1999) only found western larch thriving in large openings and concluded, "[I]n the absence of disturbances that create moderately large openings in the canopy, shade intolerant…western larch will become progressively less-well represented." More information about western larch post-fire succession is available in Chapter Three.

Table 11: Western larch importance values within six successional gradients (Habeck 1968)

Successional Gradient Segment	I	II	III	IV	V	VI
Tree Importance Value	25.8	75.2	109.0	46.2	42.2	29.8
Sapling Importance Value	40.5	9.6	0	0	0	0

D. LANDSCAPE-SCALE RESEARCH

Research Natural Areas (RNAs) within the National Forest system are intended for research at landscape, community, ecosystem, population, species, and genetic levels (Evenden and others 2001; Moeur 1992). Because these areas are important as reference sites (Evenden 1995), an effort is made to maintain natural ecosystem conditions in these areas. Though scientific and educational uses are encouraged, recreational and commercial uses are generally not allowed (Schweitzer and others 1975). Over 300 RNAs have been established in the United States, some of which include western larch forests (Table 12) (Evenden 1995).

Other areas where landscape-scale western larch research has been completed, is underway, or is likely in the future, include the Bob Marshall Wilderness (Gabriel 1976), Glacier National Park (Parker 1982, 1987), and the Swauk Late Successional Reserve in Washington (Camp 1999; Camp and others 1997).

The landscape analysis system, stand diagnosis system, stand culture system, and prescribed fire system are other tools that are available or under development for making information on larch forests in the Northern Rockies more accessible and understandable (Chew and Reinhardt 1995).

Table 12: Research Natural Areas with western larch-dominated forests (Evenden 1995, Evenden and others 2001, Moeur 1995):

RNA	**National Forest**
Idaho	
Aquarius	Clearwater
Bear Creek	Payette
Canyon Creek	
Cuddy Mountain	Payette
Hunt Girl Creek	Idaho Panhandle
Montford Creek	Idaho Panhandle
Tepee Creek	
Upper Fishhook	Idaho Panhandle
Upper Shoshone Creek	Idaho Panhandle
Montana	
Bass Creek (proposed)	Bitterroot
Barktable Ridge (proposed)	Lolo
Big Creek	Kootenai
Calrton Ridge	Lolo
Coram	Flathead
Lower Ross Creek (proposed)	Kootenai
Petty Creek	Lolo
Plant Creek	Lolo
Pyramid Creek	Lolo
Swan River	Flathead
Ulm Peak	Kootenai
Wolf-Weigel	Kootenai
Oregon	
Canyon Creek	Malheur
Indian Creek	Wallowa Whitman
Metolius	Deschutes
Mill Creek	Mt. Hood
Ochoco Divide	Ochoco
Rainbow Creek	Umatilla
Washington	
Meeks Table	Wenatchee
Salmo	Colville

CHAPTER THREE

WESTERN LARCH AND FIRE

A. FIRE ECOLOGY

Fire is an important part of western larch's ecology, and the species is considered the most fire-resistant tree in its range. Without fire or other stand replacing disturbance, western larch will not regenerate successfully and will eventually be replaced by more shade-tolerant species (Arno and Fischer 1995; Bacon and Dell 1985; Brown and Davis 1973; Franklin and Dyrness 1973; Martin and Dell 1978; Minore 1979; Schmidt and Shearer 1995; Smith and Fischer 1997).

1. Fire Adaptations

Western larch is well adapted to survive fire and to quickly colonize recently burned areas. Minore (1979) ranked western larch as the most fire resistant tree in British Columbia, Washington, Oregon, and Idaho. Though western larch seedlings, saplings, and poles are susceptible to fire, trees that are 150 to 200 years old or older are able to survive all but the most severe fires (Brown and Davis 1973; Schmidt and Shearer 1995). It is common for a handful of mature western larch trees to be the sole survivors after fire (Brown and Davis 1973), and individuals often survive multiple fires (Arno 1976; Arno and others 2000; Barrett and others 1991).

Surviving fire

The species' extremely thick basal bark protects its cambium from overheating (Arno and Fischer 1995; Brown and Davis 1973; Camp 1999; Fischer and Bradley 1987; Flint 1925; Miller 2000; Schmidt and Shearer 1995; Shearer 1980a; Starker 1934; Volland and Dell 1981). Minore (1979) ranked western larch's bark in the most fire resistant category and its foliage in the least resistant category. Low resin content and light lichen growth also decrease flammability (Arno and Fischer 1995; Schmidt and Shearer 1995; Starker 1934). Western larch's characteristic high, open crown; open stand habit; and self-pruning lower branches minimize ladder fuels and risk of crown fire (Arno and Fischer 1995; Brown and Davis 1973; Fischer and Bradley 1987; Flint 1925; Graham and others 1995; Schmidt and Shearer 1995; Starker 1934). In addition its deep roots are protected from surface and ground fires (Brown and Davis 1973; Flint 1925; Graham and others 1995; Starker 1934).

Needles of western larch are relatively small, which minimizes accumulation of surface litter (fuel) at the base of trees and decreases their flammability. And because western larch is deciduous and its needles are never more than five months old, they maintain a higher water content than other conifers' needles that are replaced every two or three years (Arno and Fischer 1995; Brown and Davis 1973; Flint 1925; Schmidt and Shearer 1995; Starker 1934). Since western larch replaces its needles annually anyway, it is also better adapted to tolerate defoliation than other conifers (Arno and Fischer 1995; Bacon and Dell 1985; Davis and others 1980; Fischer and Bradley 1987; Martin and Dell 1978).

Postburn colonization

Western larch survivors quickly reseed burned-over areas (Arno and Fischer 1995; Fischer and Bradley 1987; Graham and others 1995; Larsen 1929; Schmidt and Shearer 1995; Shearer 1980). On mineral soil, such as that left after fire, western larch seedlings develop rapidly and outgrow competitors (Arno and

Fischer 1995; Fischer and Bradley 1987; Graham and others 1995; Larsen 1929; Schmidt and Shearer 1995; Shearer 1980).

The species is considered a residual colonizer, in that fire-killed western larch can disperse viable seed if current year mature cones are present at the time of the fire (Arno and Fischer 1995; Shearer and Stickney 1991; Stickney and Campbell 2000).

Western larch seeds can disperse over long distances, allowing trees in nearby stands to reseed even if no onsite seed source is present (Fischer and Bradley 1987). If fire occurs after seedfall, destroys mature cones, or if seed crops fail (as they often do from spring frost), long distance dispersal from offsite mature western larch becomes critical for naturally regenerating burned areas (DeByle 1981; Steele and Geier-Hayes 1995). Since western larch is a very long-lived and fire-resistant species, a potential seed source remains in the area for centuries once it has established (Arno and others 1995).

2. Fire Regimes

Wildfires have occurred in western larch forests for over 10,000 years (Arno and Fischer 1995; Carlson and others 1995), and frequency and severity of fires vary with elevation, aspect, and habitat type. Prior to human intervention in fire regimes, western mixed conifer forests burned every five to 300 years. Light to moderate surface fires every six to 15 years were typical in low elevation ponderosa pine and Douglas-fir habitat types. Open, park-like stands resulted from these frequent fires that reduced fuel accumulation, prevented establishment of true firs, and avoided overstocked stands. At higher elevations, more intense fires occurred at 100- to 300-year intervals. These severe surface or crown fires created even-aged stands of seral species such as western larch, lodgepole pine, and western white pine (Seidel and Cochran 1981).

Barrett and others (1991) suggest two fire regimes for western larch forests: mixed-severity fires every 25 to 75 years and stand-replacing fires at 120- to 350-year intervals. While the species is primarily associated with these regimes, frequent surface fire regimes can also support western larch populations (Arno 2000). For example, historically, following intense stand-replacing fires in mesic to moist habitats of the northern Rocky Mountains, even-aged western larch stands often developed, while in drier habitats, western larch was maintained by frequent surface fires that minimized competition (Antos and Habeck 1981; Habeck and Mutch 1973). Table 13 summarizes typical natural fire return intervals for some habitat types in which western larch is found.

Table 13: Fire regimes for western larch ecosystems (Scher 2001)

Community or Ecosystem	Fire Return Interval Range (years)
grand fir	35-200 (Arno 2000)
Rocky Mountain juniper	< 35 (Paysen and others 2000)
western larch*	25-350 (Antos and Shearer 1980,Arno 1976,Arno 1985,Arno 1988,Arno 2000,Arno and Davis 1980,Arno and Fischer 1995,Arno and others 2000,Arno Scott Hartwell 1995,Barrett 1986,Barrett and others 1991,Davis 1980,Habeck 1990)
Engelmann spruce-subalpine fir	35 to > 200 (Arno 2000)
Rocky Mountain lodgepole pine*	25-300+ (Arno 2000,Romme 1982)
interior ponderosa pine*	2-30 (Arno 2000,Baisan and Swetman 1990,Laven and others 1980)
Rocky Mountain Douglas-fir*	25-100 (Arno 2000,Arno and Gruell 1983,Arno Scott Hartwell 1995)
western redcedar-western hemlock	> 200 (Arno 2000)
mountain hemlock*	35 to > 200 (Arno 2000)

*fire return interval varies widely

Frequent understory fires

Warm, dry sites at the lower elevations (3,000 to 5,000 feet (900-1500m)) of western larch's range, including Douglas-fir, ponderosa pine, and grand fir habitat types, in western Montana have been characterized by frequent, low intensity surface fires occurring at 10- to 30-year intervals. Stand replacing fires occurred in some of these stands at 150- to 400-year intervals (Arno 1976, 1980, 1988; Arno and Fischer 1995; Freedman and Habeck 1985; Habeck 1987 1990; Habeck and Mutch 1973).

In ponderosa pine-western larch habitat in Pattee Canyon near Missoula, Montana, fire scars indicated that from 1557 to 1918, the average fire return interval was 7.1 years. Fires occurred an average of every five to 10 years from 1750 to 1850, and in 10- to 20-year intervals from 1850 through 1900. After 1900, both the intensity and frequency of fires were reduced until high intensity fires swept through north slope of the canyon in 1977 and south slope in 1985 (Habeck 1990).

In the Flathead National Forest of western Montana, underburning occurred on average every 20 to 30 years in even-aged ponderosa pine-western larch stands before 1900, with stand replacing fires occurring at 150- to 400-year intervals. From 1735 to 1900 in the grand fir habitat type of western Montana, an average fire return interval of 17 years (range 3-32) maintained western larch as the most abundant overstory tree, followed by lodgepole pine and Douglas-fir. Western larch was also found on three Douglas-fir habitat type sites with average intervals of seven (range 2-28), 16 (range 4-29), and 19 (range 2-48) years (Arno and others 1995b). In the moist phase of Douglas-fir-ninebark habitat, surface fires every 10 to 50 years resulted in open, mature forests of Douglas-fir, western larch, and ponderosa pine (Arno and others 1985).

Arno's (2000) literature review reported that understory fire regimes prior to 1900 in ponderosa pine-mixed conifer habitat types of western North America favored western larch and other fire resistant species such as ponderosa pine. From 1600 to 1900 in several relict habitat types where western larch occurs in western Montana, fire return intervals averaged 27 (range 17-35) years in the Douglas-fir-big huckleberry type, 25-30 years in the Douglas-fir-dwarf huckleberry type, and 24 (range 9-42) years in the subalpine fir-queencup beadlily type (Arno 1988).

Mixed-severity fires

Much of the northern Rocky Mountains are characterized by 30- to 100-year-interval fires of varying severity, which favor open stands of western larch and Douglas-fir in Douglas-fir, western larch, and lodgepole pine habitat types (Arno 2000; Arno and others 2000). In the Bob Marshall Wilderness, Montana, for example, western larch-Douglas-fir and ponderosa pine forest types were historically maintained by mixed severity fire regimes. Many live western larches in this area had one to three fire scars, and one was found with four scars. Fire return intervals in this area are nearly twice as long as historic mean intervals (Arno and others 2000). On dry subalpine fir and cool, moist Douglas-fir habitat types dominated by western larch, lodgepole pine, and Douglas-fir, average fire return intervals ranged between 30 and 75 years. Severity varied from understory burns to stand-replacing fires (Arno and Fischer 1995).

In western larch-Douglas-fir forests of the North Fork of the Flathead River drainage in Glacier National Park, Montana, mean fire frequency from 1650 through 1935 was 36 years in relatively dry sites and 46 years in relatively moist sites. In the drier areas, up to seven understory fires occurred between stand-replacing fires, which occurred on average every 141 years. On moister sites, only one or two understory fires occurred between the less frequent stand-replacing fires (186-year mean intervals) (Barrett and others 1991).

Fire-free intervals in western redcedar-western hemlock forests of northern Idaho ranged from 50 to 100 years with varied intensity. In subalpine fir habitat type, low to medium intensity fires occurred at intervals greater than 150 years (Arno and Davis 1980).

Infrequent stand-replacement fires

In western larch-Douglas-fir forests of northwestern Montana, average fire return intervals from 1735 to 1976 were 120 years in valleys and montane slopes and 150 years for subalpine slopes. Most fires were small and of moderate intensity with occasional patches of high intensity. A few stands had as many as six fires during the period studied, most stands had only one. A trend of decreasing mean frequency with increasing elevation was noted. Fires on north aspects were less frequent but more intense, and multiple burns occurred primarily on south-facing slopes. In these forests, single burns of low to moderate intensity thinned the overstory and tended to favor regeneration of mixed conifers with patches of seral species, while single intense burns resulted in even-aged forests of seral species. Intense, repeated burns with a fire return interval less than 50 years created shrubfields or homogeneous stands, usually of lodgepole pine (Davis 1980).

From 1650 to 1935, relatively moist western larch-Douglas-fir forests in Glacier National Park had stand replacement fires at mean intervals of 140 to 340 years (Barrett and others 1991). In subalpine fir and Engelmann spruce habitat types in the Middle Fork of the Flathead River drainage of southwest Glacier National Park, Montana, lodgepole pine and western larch stand-replacement intervals were generally 150 to 300 years but as short as 25 years (Barrett 1986), and in grand fir habitat in the Swan Valley of Montana, stand-replacing fires occurred in average 150-year intervals, ranging from less than 20 to more than 300 years (Antos and Habeck 1981; Antos and Shearer 1980).

Prior to 1900, moist, lowland western redcedar-western hemlock sites that burned every 300 to 500 years were usually followed by stands of western white pine or western larch (Habeck 1990). Moist sites of grand fir, subalpine fir, western redcedar, and western hemlock habitat types in, which were dominated by western larch, lodgepole pine, Douglas-fir, and Engelmann spruce, burned primarily as stand-replacement fires with average fire return intervals of 120 to 350 years (Arno and Fischer 1995).

B. FIRE EFFECTS

1. Immediate Fire Effect

Mature western larch trees are more fire-resistant than any other species in their range. A model presented by Peterson and Ryan (1986) predicts zero probability of western larch (13 inches (34 cm) diameter) mortality after fire with a scorch height of 33 feet (10 m). Unless a smoldering surface fire or ground fire girdles boles or the buds are killed by torching, mature western larch trees will survive most fires (Arno and Fischer 1995; Fischer and Bradley 1987; Habeck and Mutch 1973).

A severe fire in the Bitterroot National Forest, Idaho, killed nearly all grand fir, Douglas-fir, and western redcedar, but most western larch over eight inches (20 cm) d.b.h. survived (Humphrey and Weaver 1915). After low-severity surface burns in ponderosa pine forests of eastern Oregon, 64 percent of western larch showed no negative effects, 33 percent were scarred at the base with wood exposed, and two percent burned off at the base. No trees were killed by burning material around the base of the trees (Munger 1914). One year after underburning shelterwood units in Idaho, western larch overstory mortality was seven percent (Simmerman and others 1991).

Though mature western larch trees are remarkably fire tolerant, seedlings and saplings are readily killed by fire (Habeck and Mutch 1973). They are less tolerant than those of ponderosa pine (Bacon and Dell 1985; Martin and Dell 1978), but may tolerate low-severity underburning better than white fir, lodgepole pine, or Douglas-fir (Volland and Dell 1981).

2. Survivors

Young western larch trees wounded by surface fires often heal and survive for centuries (Arno and Fischer 1995). After prescribed underburning of Douglas-fir-western larch forest in western Montana, western larch's radial growth was reduced in the first year postfire, but increased over the following seven years, suggesting that decreased competition may have enhanced western larch growth as other trees died off (Reinhardt and Ryan 1988). Peterson and Ryan (1986) reported that death of dormant buds on burned western larch occurred 20 percent lower down the stem than foliage death.

3. Early Regeneration

Regeneration of western larch after fire depends on site conditions and fire intensity. For example, after moderate fires in grand fir habitat of the Blue and Wallowa Mountains of northeastern Oregon, western larch in cool, moist areas had increased by the first and the fifth years. After severe fires, the species decreased after the first year, but increased by postfire year five. In warm, dry grand fir habitats, moderate fires resulted in a decrease after the first year and no change by the fifth year postfire, while severe fires caused a decrease in western larch after the first year and an increase by five years postfire (Table 14) (Johnson 1998).

Typically, western larch establishes in the first season after fire (Antos and Shearer 1980). In the Flathead National Forest of northwestern Montana, western larch began colonizing both wildfire and prescribed burn sites during the first year postfire (Shearer and Stickney 1991; Stickney 1982). Up to five inches (13 cm) of first year postburn seedling growth was reported after spring, summer, and fall burning of white fir sites on Wallowa-Whitman National Forest, Oregon (Petersen and Mohr 1984).

Table 14: Western larch response to burning in grand fir associations (Johnson 1998)

Plant Association	**Fire Severity**	**Western larch percent cover**			
		Pre-fire	**first year postfire**	**5th year postfire**	**10th year postfire**
Grand fir-beadlily	Severe*		2	5	
Grand fir-twinflower	Moderate	15	5	5	
Grand fir-grouse whortleberry	Severe*		0		13
Grand fir-grouse whortleberry	Moderate		0	0	

** indicates that fire killed all trees*

Rapid and abundant western larch regeneration and dominance is favored by fires that expose mineral soil and reduce competition, especially on north-facing slopes (Antos and Shearer 1980; Schmidt 1969). After fires in 1910 and 1919 in Coeur d'Alene National Forest, Idaho, western larch had restocked up to 200 seedlings per acre (500 seedlings/ha) on the north aspect of the study area by the fall of 1923. Western larch seedlings accounted for 83 percent of conifer seedlings present on all slopes and 88 percent of those on the north-facing slope (Larsen 1925). Likewise, Latham and others (1998) found that in general, fires that resulted in open sites, relatively free of vegetation, with full sun, moving shade, and a mineral soil seed bed favored the development of western larch forests. In these conditions, western larch seedlings were generally able to establish quickly and grow taller than other vegetation. Where tree establishment was delayed, however, shrubs were able to establish and suppress western larch.

Overstocking may result on some sites if too much mineral soil is exposed (DeByle 1981; Harrington 2000; Schmidt 1969; Shearer 1975). Old skid trails also often support high densities of western larch seedlings, but the compacted soil may not allow trees to grow as well as on other sites. Good sites for potential western larch establishment decrease as regeneration of a burned site progresses (Antos and Shearer 1980).

C. POST-FIRE SUCCESSION

Western larch is considered fire dependent because without fire it is replaced successionally by more shade tolerant species (Habeck 1990). In fact, the presence of western larch in a stand is a strong indication that the stand formed after a stand-replacing fire (Camp and others 1997).

Regeneration of western larch after fire depends on site conditions and fire intensity. For example, in the Douglas-fir zone in western Montana, various combinations of western larch, ponderosa pine, and Douglas-fir establish after disturbance, and the relative abundance of each depends heavily on available moisture (Habeck 1967b). In the Intermountain Region of the northern Rocky Mountains, lodgepole pine is commonly associated in the upper part of the Douglas-fir zone, while in the Inland Maritime Region both lodgepole pine and western white pine are early postfire colonizers (Habeck 1987).

After fire, western larch must establish rapidly. Insufficient sunlight or too little exposed mineral soil prevents western larch establishment, allowing development of shrubs or more shade-tolerant tree species that precludes future western larch establishment and development (Antos and Shearer 1980; Tippets 1996; Larsen 1929; Schmidt and Shearer 1995; Steele and Geier-Hayes 1995).

Western larch benefits from periodic surface fires that kill competing shade-tolerant conifers (Arno and others 1995b). Often, stand-replacing fires favor western larch over its competitors because western larch is most likely to survive and provide an onsite seed source, while less fire-resistant competitors must rely on offsite sources or unburned islands of trees (Antos and Habeck 1981; Arno and Fischer 1995; Shiplett and Neuenschwander 1994). Fires that occur after autumn seedfall, however, will destroy onsite western larch seed, and regeneration of western larch will have to rely on offsite seed sources (DeByle 1981).

Once established, this long-lived species may dominate the area for as long as 150 to 350 years even in the absence of fire (Arno and Fischer 1995; Shiplett and Neuenschwander 1994). Western larch also benefits from low to moderate intensity surface fires that kill competing shade tolerant conifers (Arno and Fischer 1995; Arno and others 1995b; Carlson and others 1995), creating spaces for western larch seedlings and allowing already established trees to thrive.

Western larch and lodgepole pine are early seral species that often compete in the same recently burned areas. On Coram Experimental Forest in northwestern Montana, single, high intensity burns in western larch-Douglas-fir habitat thinned the overstory and favored regeneration of western larch, Douglas-fir and lodgepole pine, while multiple severe burns tended to promote lodgepole pine (Sneck 1977).

In general, lodgepole pine performs better on drier or more exposed sites (Shiplett and Neuenschwander 1994), or in younger stands (Antos and Habeck 1981; Antos and Shearer 1980). Due to western larch's later age of first seed production and longer lifespan, it may be favored over lodgepole pine on sites that burn less frequently (Antos and Shearer 1980; Sneck 1977). Fires in the subalpine forest zone usually result in lodgepole pine-dominated early successional communities, with western larch as a minor associate (Habeck 1967b). Western larch-lodgepole pine stands in grand fir sites of northwestern Montana with as little as 10 percent western larch overstory eventually can be dominated by western larch, and if lodgepole pine seed is minimal or entirely absent and a western larch seed source is available, a larch-dominated stand will usually result (Antos and Habeck 1981).

Due to western larch's later age of first seed production and longer lifespan, it may be favored over lodgepole pine in stands that burn less frequently (Antos and Habeck 1981; Antos and Shearer 1980; Minore 1979; Sneck and Davis 1977). For example, Antos and Habeck (1981) found that western larch and lodgepole pine establish following intense fires in grand fir habitat of the Swan Valley of western Montana. In stands that were over 150 years old at the time of fire, western larch tended to dominate the early succession vegetation, whereas lodgepole pine was favored in younger stands. On the other hand, in the cedar-hemlock and Douglas-fir zones of northwestern Montana, Habeck

(1967b) reported that lodgepole pine was usually the most common pioneer after a single fire, and western larch abundance tended to increase after a second fire.

Sometimes, neither species will establish, and a shrubfield will develop, followed by mixed stands of Douglas-fir, grand fir, western white pine, and spruce (Antos and Shearer 1980). They found that moisture availability and stage of succession at the time of fire were major factors influencing postfire stand composition of disturbed grand fir sites in the Swan Valley, Montana.

In ponderosa pine-Douglas-fir forests of the inland northwest, the FIRESUM model predicts successful regeneration of ponderosa pine with a 10- to 20-year fire return interval. More severe fires at 50-year intervals predict western larch dominance for 150 years, then an increase in ponderosa pine, and Douglas-fir dominance after 200 years. Without fire, Douglas-fir dominates the understory and eventually the overstory, limiting or precluding regeneration of western larch and ponderosa pine (Keane and others 1990).

3. Absence of Fire

Prior to 1900, fire maintained western larch as a dominant seral species in various habitats (Arno 1996; Arno 1988), and lack of periodic fires may limit western larch regeneration (DeByle 1981). Fire suppression in the last century has favored thickets of suppressed shade-tolerant conifers (Arno 1976; Arno 1988; Arno and Fischer 1995), and large areas in and around the western larch habitat type are now characterized by crowded and stagnant stands, which result in a decline in the vigor of all trees (Arno and Fischer 1995). There is also an increased risk of high intensity wildfires on these sites (Arno 1996; Arno 1976; Habeck 1990). Reduced fire frequency and intensity has been linked to the decline of western larch habitat in Idaho, Montana, Oregon, and Washington (Arno and Fischer 1995; Carlson and others 1995; Habeck 1990; McCune 1983).

Due to a reduction in fire since 1900, Pattee Canyon near Missoula, Montana, which once was a "parkland mosaic of ponderosa pine and western larch" sustained by frequent fires, has been converted to a "closed-canopied Douglas-fir forest" with a thick understory of Douglas-fir saplings and pole-sized trees (Habeck 1990). This understory can provide ladder fuels, resulting in a crown fire that may kill mature trees. If fire does not occur before the remaining trees die in these areas, or if ladder fuels create a crown fire that burns intensely enough to kill the remaining trees, the on-site western larch seed source may be eliminated. However, if a seed source remains after fire, western larch may thrive in the postfire mineral seedbed with reduced competition (Habeck 1990, 1994).

Likewise, near Seeley Lake in northeastern Missoula County, Montana, western larch trees are 600 to 700 years old (and up to four or five feet in diameter) and have multiple scars indicating a history of fires in the area. The Douglas-fir understory will likely eventually replace western larch unless fire occurs before these unusually old trees die (Habeck 1967a). And in Bear Creek Canyon of the Bitterroot Mountains, Montana, where old western larch are prevalent and younger ones less abundant, and where larch dwarf mistletoe has infected most trees, the species is near extinction due to lack of fire or other disturbance (McCune 1983). A study of general land office records for western Montana indicated that a reduction in fire has allowed Douglas-fir to gain dominance over western larch and ponderosa pine in the Fort Missoula Timber Reserve (Habeck 1994),

Though fire is a necessary component of western larch ecology, the timing or intensity of some fires may be detrimental. For example, three fires in a 30-year period (1889, 1910, 1919) nearly eliminated western larch from the Foolhen Creek drainage in the Bob Marshall Wilderness, Montana, an area that once supported old-growth stands of Douglas-fir and western larch. Most surviving trees in the area are 200 to 300 years old, though some western larch established in mixed stands after the 1919 fire. In the Dahner Creek drainage nearby, western larch is extremely scarce, most likely a result of fires that occurred at five- to 10-year intervals from 1889 to1904. Several trees in this area appear dead but have one or two cone-producing limbs, which probably produced the young western larch that are mixed with Douglas-fir and lodgepole pine. Most western larch in this area are probably over 200 years old (Gabriel 1976).

D. FIRE MANAGEMENT CONSIDERATIONS

Prescribed underburning in western larch-Douglas-fir forests is feasible (Norum 1976). An average of 15 percent of the overstory trees were killed in the plots. Within the range of fuel loadings in this study, fires were most manageable and still effective when the moisture content of zero to one inch (0-2.5 cm) dead fuels was around 15 percent (Norum 1975a, 1975b). Strip ignition helped overcome control and ignition problems caused by discontinuous concentrations of heavy fuels. Underburning requires attention to the form, moisture status, and amount of living vegetation (Norum 1976; Norum 1977).

1. Prescribed Burning

Fire is an important management practice for maintaining western larch (Arno and Fischer 1995,Carlson and others 1995,Habeck 1990,McCune 1983). Ideally, prescribed burns should expose well-distributed patches of mineral soil and reduce sprouting potential of competitors (Harrington 2000; Schmidt 1969; Shearer 1975). However, even areas with very little burned surface result in significantly better western larch regeneration than unburned sites (Arno and Fischer 1995; Shearer 1989a). In good seed crop years, overstocking may result in mesic habitats where too much mineral soil is exposed, and thinning may be necessary to facilitate a vigorous stand (DeByle 1981; Harrington 2000; Schmidt 1969; Shearer 1975). Harsh sites with poor regeneration potential, such as those on steep, harsh sites, may require planting after burning (Arno and Fischer 1995; DeByle 1981).

Harrington (2000) and Norum (1977) provide detailed recommendations for prescribed burning in western larch-Douglas-fir forests. Based on studies of fire and harvest regimes, Antos and Shearer (1980) make recommendations for management practices on grand fir-queencup beadlily habitat type in northwestern Montana.

Timing and Site Conditions

The timing of prescribed burns is important for western larch site preparation; large fuels should be dry and soil moisture low in order to expose mineral soil (Arno and Fischer 1995; DeByle 1981; Norum 1977; Noste and Brown 1981; Shearer 1975). Norum (1981) reported that 10 to 17 percent moisture content in small diameter (< 4 inches (<10 cm)) fuels is a safe and effective range for burning in western larch-Douglas-fir habitat. Spring and early summer fires usually burn only the surface of the duff layer, while late summer or early fall fires after dry summers tend to be more effective at exposing enough mineral soil for western larch regeneration. August and early September, before the fall rains, are the best times for burning north-facing slopes, but on other aspects, there is more flexibility for timing a successful burn (Arno and Fischer 1995; DeByle 1981; Norum 1977; Noste and Brown 1981; Shearer 1975). However, if precipitation occurs, fuels and duff need to dry for several days. At Newman Ridge, moderate intensity fires removed most of the duff and prepared an adequate seedbed. At Miller Creek, the same intensity fire exposed less mineral soil because the duff was thicker and wetter (DeByle 1981).

Habitat type and site conditions alter the amount of duff removal needed for western larch regeneration. On mesic habitat types severe fires that expose a high proportion of mineral soil, followed by good seed years, lead to dense stocking. On steeper slopes with drier conditions, such as at Newman Ridge, residual duff layers have an adverse impact on the survival of seedlings (Debyle 1981).

Timing of seed dispersal should also be considered when planning fall fires; burning before seedfall is preferable. In a plentiful seed year, dispersed seed could be destroyed by fires after early September at lower elevations and a few weeks later at higher elevations (DeByle 1981). Depending on site conditions, removing duff from bases of western larch trees to prevent cambium and root damage and/or thinning the understory to reduce ladder fuels may be necessary prior to burning (Arno and others 1997; Harrington 2000; Shearer 1975).

Fire Intensity

An adequate seedbed for western larch usually results from moderate intensity fires in dry duff. High intensity fires may expose too much mineral soil and result in overstocking (Arno and Fischer 1995; DeByle 1981). Prescribed burning after clearcutting or shelterwood cutting is sometimes used to mimic the effects of severe wildfires on western larch habitat (Arno and Fischer 1995; Tippets 1996).

Reinhardt and Ryan (1988a) found western larch seedlings established best on sites burned by the hottest fires in a Douglas-fir-western larch stand in western Montana. Prescribed underburns in western larch stands can result in a significant (p = 0.04) increase in individual tree relative radial increment compared to unburned stands. However, growth of western larch in these poorly growing stands continued to be slow (approximately 0.04 inche (1 mm) per year). Growth, even in trees with fire damage, was not reduced by the fire, and fire may be a useful tool for fuel reduction or other purposes in such stands.

Underburning may also lead to consistent successful natural regeneration but requires careful attention to fuel and site conditions (Arno and Fischer 1995; Norum 1976; Petersen and Mohr 1984; Schmidt 1969). Harvey and others (1980b) found burning to remove slash reduced ectomycorrhizal activity after partial cuts in western larch-Douglas-fir forests of northwestern Montana. They recommend against burning to remove slash on harsh sites where understory competition may limit conifer germination or where soil organic matter is low. Instead, underburning is better suited for areas where excessive regeneration is expected or where understory vegetation is desired, especially if burn conditions are chosen to limit duff reduction, which in turn will limit conifer (including western larch) germination.

2. Models

Reinhardt and Ryan (1988a, 1989) present a model for predicting postfire mortality of western larch and six other western conifers using bark thickness and percent crown volume. Desired levels of mortality can be predicted using tree species, diameter, height and crown ratio, and maximum allowable flame length. FIRE-BCG simulates fire succession on coniferous forest landscapes of the northern Rocky Mountains, including western larch habitat (Keane and others 1996), and FIRESUM models tree establishment, growth, mortality, fuel accumulation, fire behavior, and fuel reduction in ponderosa pine-Douglas-fir forests of the Inland Northwest (Keane and others 1990).

CHAPTER FOUR

WESTERN LARCH AS A RESOURCE

A. GROWTH AND YIELD

Western larch has a long lifespan and is among largest larches in the world (Ostenfeld and Larson 1930b). Western larch stands and individual trees attain their greatest growth rates in the early years, tapering off as competition reduces available light, moisture, and nutrients (Cochran and Seidel 1995, 1999; Schmidt and Larson 1989). Seedlings grow faster than any other conifer in central Idaho, attaining a height of 4.5 feet (1.4 m) in six years (Steele and Geier-Hayes 1995). Cultural practices can improve and prolong growth of individual trees if done before crown lengths have been reduced and tree vigor has declined significantly (Schmidt 1966). Bailey and Ware (1983) present a thinning index and thinning multiplier for use in predicting growth and yield of thinned stands (including western larch stands).

1. Height

Height growth of dominant and codominant western larch trees is rapid early in the life of the stand. Site index or height-over-age curves for western larch show that dominant and codominant trees grow about 16 feet (5 m) between age 20 and 30 on average sites (site index 50-60). Later on, between age 80 and 90, the dominant and codominant trees grow at only about one-third the former rate. Another comparison shows that the dominant and codominant trees on average sites attain about 78 percent of their 200-year height in the first 100 years (Deitschman and Greene 1965).

Western larch annual shoot growth results from predetermined growth and free-growth, and both modes of growth are influenced by genetics as well as environmental changes from year to year (Joyce 1985, 1987). Western larch's rapid height growth may indicate allocation of resources to early growth rather than early seed production, which would explain the species' relatively advanced age of first reproduction compared to other early successional species. Western larch extension growth was significantly greater than that of six other northwestern conifers. This characteristic and low shade tolerance were both associated with early successional species studied (Turner 1985).

Western larch height growth rates are somewhat slower near the southern end of its range. At 50 years of age western larch's average height is 65 feet (20m) in central Idaho (Steele and others 1981, Steele and Geier-Hayes 1987), compared with 80 feet (24 m) in northern Idaho (Cooper and others 1987, 1991) and northwestern Montana (Pfister and others 1977). In Oregon and Washington, western larch site index varied from 40 to 135 square feet per acre per year (9-31 m^3/ha/yr)—a 3.4-fold difference, indicating that productivity may also vary by a 3.4-fold difference (Hall 1995).

For the first 90 to 100 years, western larch height growth exceeds that of all other Northern Rockies conifers except for lodgepole pine, which grows nearly as fast as for the first 50 or 60 years. At Coram Experimental Forest in Montana, western larch growth rates until age 20 were twice as fast as Douglas-fir and three to four times greater than for subalpine fir and Engelmann spruce. Western larch grows faster than western white pine, western hemlock, and western redcedar in more moist sites of northern Idaho, though differences between western larch and western white pine growth rates are minimal on thinned sites. Because western larch is so intolerant of shade, attaining this height advantage over associated species is crucial to its survival. Height growth slows after 100 years (Deitschmann and Green 1965; Schmidt and others 1976; Schmidt and Shearer 1990; Watt 1960).

Site

Ecological habitat strongly influences site productivity and height growth of western larch (Roe 1967). Mean site indices for some ecological habitat types, based on Daubenmire's (1952) classification of ecological habitats and height/age curves from Cummings' (1937a) data, are summarized in Table 15.

Site productivity accounts for the largest share of the variation in height growth of larch throughout its range. Site index curves for larch (base age of 50) show heights at age 100 ranging from 20 m (65 feet) on low sites to 40 m (130 feet) on high sites (table 16). Average site indices for larch on different ecological habitat types are given in Table 17. (Schmidt and Shearer 1990)

Physiographic position, directly interrelated with habitat type, also influences height growth. Larch grows most rapidly in height on the deep, moist soils of valley bottoms and lower north and east slopes, but poorly on the upper south and upper west slopes (35) (Table 18) (Schmidt and Shearer 1990).

Table 15: Mean site indices by ecological habitat type

Ecological habitat type	Mean site index	Confidence interval (p=0.99)
Subalpine fir-beargrass	49.1	±2.08
Subalpine fir-Oregon boxwood	58.2	±2.56
Western hemlock-Oregon boxwood	66.3	±1.35
Western redcedar-Oregon boxwood	66.3	±1.35
Grand fir-Oregon boxwood	66.3	±1.35
Douglas-fir-ninebark	62.2	±4.46
Douglas fir-pinegrass	54.6	±1.50

Table 16: Height of average dominant and co-dominant western larch by age and site index (Schmidt and Shearer 1990)

	Site index at base age 50 years		
Age	12.2 m or 40 ft	18.3 m or 60 ft	24.4 m or 80 ft
yr	*m*	*m*	*m*
20	3	4	6
40	9	14	19
60	14	21	29
80	17	26	35
100	20	30	40
yr	*ft*	*ft*	*ft*
20	9	14	19
40	31	47	63
60	47	70	94
80	57	86	115
100	65	97	130

Table 17: Average site indices for western larch by habitat type (Pfister and others 1977; Schmidt and Shearer 1990)

Ecological habitat type	Average site index at base age 50 years	
	meters	feet
Northern Idaho and Washington:[1]		
Subalpine fir-beargrass	14.9	49
Subalpine fir-Oregon boxwood	17.7	58
Western hemlock-Oregon boxwood; Western redcedar-Oregon boxwood; Grand fir-Oregon boxwood	20.1	66
Douglas-fir-ninebark	18.9	62
Douglas-fir-pinegrass	16.8	55
Montana:		
Douglas-fir-dwarf huckleberry	18.0	59
Douglas-fir-ninebark	17.4	57
Douglas-fir-twinflower	16.8	55
Spruce-dwarf huckleberry	22.6	74
Western redcedar-queencup beadlily	19.2	63
Western hemlock-queencup beadlily	24.4	80
Subalpine fir-queencup beadlily	19.2	63
Subalpine fir-twinflower	17.1	56
Subalpine fir-menziesia	20.4	67
Subalpine fir-beargrass	15.5	51

[1] Based on Daubenmire's (1952) classification

Table 18: Average site indices for western larch by physiographic class (Schmidt and others 1976)

Physiographic class	Average site index	
	m	ft
Valley bottoms	18.9	62
Midnorth and mideast facing slopes, lower south and lower west facing slopes and benches	18.0	59
Upper north and upper east facing slopes	17.4	57
Midsouth and midwest facing slopes	16.2	53
Upper south and upper west facing slopes	13.4	44

Conditions of seedbeds affect height growth when western larch are young (Schmidt 1966). On the Priest River Experimental Forest in northern Idaho, two-year old western larch seedlings on burned seedbeds were two times taller than those on bare mineral or duff-covered soil (Haig and others 1941). At Coram Experimental Forest in Montana, western larch growing on burned seedbeds grew approximately one-third faster than those on scarified or undisturbed soil, and these growth differences continued through the teenage years (Schmidt and others 1976). Differences in nutrient availability, water infiltration, or competing vegetation may accound for the variation. Elevated levels of manganese, magnesium, nitrogen, phosphorus, and calcium were found in the upper soil layers of burned seedbeds (Haig and others 1941).

Six years after harvesting and planting in a mixed stand including western larch, western larch height and volume growth was best on disturbed ground, except for areas with rakes and tracks. Growth in non-raked treatments was best, followed by raked treatments, and finally undisturbed soil. Increased soil moisture was significantly related to increased height, diameter, and volume growth five years after treatment, suggesting that water-uptake limits affect western larch growth (Smith and Wass 1991).

Larch grows most rapidly in height on the deep, moist soils of the valley bottoms, but also grows well on mid-to-lower north and east slopes, lower south slopes, and benches. Average site indexes for five physiographic site classes measured in western Montana, northern Idaho, and eastern Washington ranged from a high of 62 feet (18.9 m) in 50 years in the valley bottoms to a low of 44 feet (13.4 m) on the upper south and west slopes (Roe 1967). A growth curve developed for western larch growing on Waits soils (Pearcy 1965) had essentially the same slope as the average curve for larch on all soils and sites, but was considerably lower. No western larch growth curves have been developed for other soil series to our knowledge.

Density

Stand density also affects height growth of western larch in very young stands (Schmidt 1966). Young stands freqhently have high densities, sometimes in excess of 35,000 trees per acre (86,500 trees/ha). For instance, at Coram Experimental Forest, dominant wetern larch in stands with 5,000 trees per acre (12,400 trees/ha) grew about one-third faster than those in stands with 35,000 trees per acre (86,500 trees/ha). Thinning of the heavily stocked stands increased height growth, but trees in these stands continued to grow relatively slowly

(Schmidt 1980a). By age 24, dominant trees in unthinned stands were 15 to 20 percent shorter than dominant trees in thinned stands, which averaged over 30 feet (9 m) tall (Schmidt 1978).

After thinning a western larch stand in northeastern Oregon, height growth varied significantly ($p < 0.05$) between study periods due to a substantial decrease during the fourth period (years 15-20). Height growth was significantly greater ($p < 0.05$) in stands thinned from below than those thinned from above. Though height growth varied little among stocking levels, increased growth at the lowest level resulted in a significant ($p < 0.05$) difference. (Seidel 1980, 1982, 1984, 1986, 1987). Over 20 years, the average height Periodic Annual Increments decreased with increased age on western larch stands thinned from below (Cochran and Seidel 1995).

Models and Equations

A wide range of equations and models are available to predict western larch height. Nigh (2001) developed a species-independent height-age model that incorporates site index, geographic region, and shade tolerance. Accuracy of height prediction was similar to species-specific models. Nigh and Brisco (1999) developed 50 equations for estimating the site index of western larch stands using breast height ages (1-50 years) based on data from British Columbia. Milner's (1992) site index and height growth curves allow prediction of height growth patterns for western larch in Montana. Cochran (1985) outlined a method to estimate site index of a stand. Steele and Cooper (1986) presented equations that can be used to predict western larch site index and height using site indices of associated species and vice versa. For stands with trees greater than 20 inches (51 cm) d.b.h., Reinhardt's (1983) curves adequately predict site index from measurements of five to 15 trees. Western larch growth tables, which according to field data comparisons are accurate to within 15 percent two out of three times, are available (Kemp and Metcalf 1948).

The Wykoff function in the Stand Prognosis Model, a refitted Wykoff function, and the Lundqvist function were tested against field data for ten species including western larch. Results indicate that either function can be used for trees less than 30 inches (76 cm) d.b.h., but the Lundqvist is recommended when dealing with large trees (Moore and others 1996). Monserud (1984) suggest that individual tree-based stand simulation models may avoid some problems associated with site index, "but only to the extent that they are driven by key factors that are related to site productivity." Brisco and Klinka (2002) tested conditional logistic, Chapman Richards, conditioned Chapman Richards, and conditioned Weibull models against western larch yield data from British Columbia. All four height growth curves were similar in their degree of fit to the data, but the Chapman Richards model was the best fit overall and is therefore recommended for estimating western larch height in British Columbia.

2. Diameter

Diameter growth measured at breast height for western larch largely parallels height growth and is affected by many of the same factors (Schmidt and Shearer 1990). Western larch possesses the potential for rapid diameter growth, but overstocking, insect attacks, and dwarf mistletoe infection in natural stands often preclude full realization of this potential. Diameter growth is also influenced by site quality, tree vigor, and tree age. Some of these factors may be modified or controlled by management. Converting old-growth stands to young stands and managing on shorter rotations takes advantage of the greater growth potential of younger trees (Schmidt and others 1976).

Table 19: Potential d.b.h. of western larch trees at age 50 and at age 100 years by ecological habitat type and site index (Schmidt and others 1976)

Site index at base age 50 years				
Ecological habitat type	**Age**	**12.2 m or 40 ft**	**18.3 m or 60 ft**	**24.4 m or 80 ft**
	yr	*cm*	*cm*	*cm*
1. subalpine fir-beargrass	50	13.7	19.3	-
	100	25.1	33.8	-
2. Douglas-fir-ninebark	50	14.5	19.8	-
and pinegrass	100	26.7	35.0	-
3. subalpine fir-Oregon boxwood	50	-[1]	20.3	25.9
	100	-	35.8	44.7
4. grand fir-Oregon boxwood	50	-	20.6	26.2
	100	-	36.6	45.2
5. western hemlock-Oregon boxwood	50	-	20.8	26.2
and western redcedar-Oregon boxwood	100	-	36.8	45.2
	yr	*in*	*in*	*in*
1. subalpine fir-beargrass	50	5.4	7.6	-
	100	9.9	13.3	-
2. Douglas-fir-ninebark	50	5.7	7.8	-
and pinegrass	100	10.5	13.8	-
3. subalpine fir-Oregon boxwood	50	-	8.0	10.2
	100	-	14.1	17.6
4. grand fir-Oregon boxwood	50	-	8.1	10.3
	100	-	14.4	17.8
5. western hemlock-Oregon boxwood	50	-	8.2	10.3
and western redcedar-Oregon boxwood	100	-	14.5	17.8

[1] Dashes indicate that values are outside the data base.

Site

Diameter increment of individual crop trees varies with habitat type and stand density. In the most productive habitat types, western larch crop trees reach larger diameters than those in the less productive types under comparable stand densities. For example, 140-year old trees in stands of 60 percent normality range from a low of 15.1 inches (38 cm) d.b.h. in the least productive habitat (subalpine fir-beargrass) to a high of 20.3 inches (52 cm) in the most productive habitat (western hemlock-Oregon boxwood)—a difference of 5.2 inches (14 cm) in the average dominant larch crop trees (Schmidt and others 1976).

Potential diameter growth curves, which can serve as a guide for evaluation of tree and stand conditions, are available for various habitat types and site indices (Table 19) (Schmidt and others 1976). These projections are based on relatively open stands and indicate that by age 50, western larch may attain diameters 10.3 inches (26 cm) on high quality sites to 5.4 inches (14 cm) on low quality sites; at age 100, diameters may be 17.8 inches (45 cm) to 9.9 inches (25 cm).

Density

Stand density affects western larch diameter growth (Schmidt and Shearer 1990). Following partial cutting, residual overmature western larch respond with a moderate diameter increase on a percentage basis, but their absolute growth is still slow. Even though the diameter growth rate of residual western larch trees at Coram Experimental Forest the first five years after harvesting was 67 percent higher than during the five years before the harvest cutting, growth was still very slow (Roe 1956). Conversely, the more tolerant Douglas-fir grew faster than western larch both before and after the partial cuttings. It increased its growth rate only 42 percent after logging but still made wider rings than western larch after the partial cuttings. Removal of most of the understory trees on part of the plots five years after logging caused an additional 36 percent increase in growth rate of western larch during the next five-year period. The growth rate of western larch on the uncut control plots increased only two percent during the same period. Douglas-fir growth rate did not increase as a result of understory removal. Because this species is heavier crowned and more tolerant, it is better able to grow under competition than western larch; thus, the added effect of understory removal was not a significant factor. The growth rate of the residual western larch trees, even after logging and understory removal, did not result in a large diameter increment (Schmidt and others 1976).

Diameter growth of nine-year old western larch stands at Coram Experimental Forest that had 35,000 trees per acre (86,500 trees/ha) was half that of stands with 5,000 trees per acre (12,400 trees/ha) (Schmidt 1966). Dominant trees in the unthinned stands were still growing half as fast as those in thinned stands at ages 19 and 24 (Schmidt 1978). Other studies of 30- to 50- year old stands in Montana also found that crop-trees in unthinned stands grew at about half of their potential (Roe and Schmidt 1965).

Over 20 years, quadratic mean diameter periodic increments decreased with increasing stand density on western larch stands thinned from below. (Cochran and Seidel 1995). Thirty-year results showed that the presence of small-diameter trees reduced the growth of the largest trees (Cochran and Seidel 1999).

Fifteen years after cutting in western Montana, stands that included western larch were growing normally according to yield table estimates. Western larch diameter growth was less vigorous than that of Douglas-fir and ponderosa pine. Estimates calculated by the Forest Vegetation Simulator (FVS) (Inland Empire variant, version 6.1) were low (Schwalm and Milner 2002).

A trend of decreasing diameter growth with increasing stand density was reported 20 years after thinning from above and below in a western larch stand in northeastern Oregon. Differences between density levels were significant ($p < 0.01$) between the lowest density and all others. Thinning method did not affect diameter growth. Diameter growth was significantly ($p < 0.01$) faster during the first period compared to the other five-year periods and was slowest during the fourth. A second thinning 10 years after the first prevented the decrease in diameter growth that would have been expected as the stand aged and density increased, suggesting that uniform diameter growth can be maintained in stands up to 50 years old by repeated thinning (Seidel 1980, 1982, 1984, 1986, 1987).

Stand density affects diameter increment of crop trees as much as site quality, or habitat type. For example, at age 140 the greatest spread in average diameter of crop trees in normal stands was 4.2 inches (11 cm) (western redcedar-Oregon boxwood and western hemlock-Oregon boxwood habitat types vs. subalpine fir-beargrass habitat type); the difference in average diameter of crop-trees in stands stocked at 1.4 normality vs. stands stocked at 0.6 normality was 5.1 inches (13 cm) in the western redcedar-Oregon boxwood and western hemlock-Oregon boxwood habitat types.

Trees of high vigor in heavily cut stands with low residual volume respond best in terms of accelerated diameter growth (Roe 1950, 1951). Residual trees of low vigor increase their diameter growth slightly in stands of less than 3,000 board feet, but continue to decline in growth rate in stands having heavier reserve volumes. Diameter increments of one inch (2.5 cm) or more per decade are usually attained only within high-vigor larch trees in residual stands of 1,000 board feet or less.

Tables compiled by the Division of Silvics (1937) of the Northern Rocky Mountain Forest and Range Experiment Station show volumes per acre and diameter classes to be expected 10, 20, 30, 40 years after partial cutting in western larch-Douglas-fir stands in northwestern Montana. In general, pre-merchantable western larch exceeded 13.1 inches (33 cm) d.b.h. within 30 to 40 years after harvest.

Age and Vigor

The physiological condition of the tree, as indicated by external vigor characteristics, influences the rate of diameter increment. A study of dominant and codominant western larch crop trees throughout the Northern Rockies reported that the 10-year diameter increment decreased with decreasing vigor (Table 19). The effect of vigor is much more pronounced in older trees; only a slight difference in increment occurs between good and poor vigor classes in 10- to 20-year-old trees, but increment in the good vigor class is nearly twice that of the poor vigor class between 50 and 60 years of age (Schmidt and others 1976).

Diameter increment normally decreases with advancing age, but this decrease is less pronounced on the better sites. Rapid growth in the first decade is typical of western larch trees in stands that are not heavily stocked. Growth rates from 10 to 20 years of age differ only slightly from site index 40 to site index 80. But from 90 to 100 years of age trees on site index 40 lands grow slightly less than half as fast as those on site index 80 lands. The greater growth rates on the better sites result in substantially larger trees at harvest age. On site index 80 lands, 140-year-old trees may be 10 inches larger than those on site index 40 lands (Schmidt and others 1976). Growth response after partial cuttings in overmature stands is low, owing to old age and competition from two sources: overstory trees and understory (Roe 1956).

Table 20: Diameter increment of western larch classified by vigor and adjusted for variation due to crown length and age (Schmidt and others 1976)

Vigor	**10-year diameter increment (inches)**
Good	1.28
Medium	.91
Poor	.71

Models and equations

Max and Burkhart's stem profile model can be used to estimate tree diameter at a given height along the main stem from d.b.h. and total tree height. This estimate can then be used to estimate the number of merchantable logs in a tree. Though the model is reasonably accurate, Czaplewski and others (1989) further reduced the average error to less than 10 percent by application of a second stage model. Yield tables for western larch plantations in the Inland Empire are available, based on estimates from the Prognosis Model for Stand Development, version

5.2, including the Regeneration Establishment Model. Of the species included, western larch yields are the lowest due to lower stocking levels, slower diameter growth, and higher mortality rates (Stage and others 1988).

Formulas are available for determining outside bark diameter of western larch based on the apparently linear relationship between bark thickness and bark diameter at breast height (Spada 1960). Omule and Kozak (1989) present regression coefficients for calculating breast height diameter of western larch from stump measurements, and Lange (1973) presents equations and tables for d.b.h. and stump diameter for western larch, based on data from Lubrecht Experimental Forest, Montana. Rapraeger (1941) also presented charts relating stump size to diameter for normally shaped western larch trees.

3. Basal Area

Stand basal area in larch forests rises rapidly up to about age 40, decelerates, then nearly levels off after age 100. For the first 100 years, basal area increases about 3 square feet per acre on high quality sites, and for the next 100 years basal area increase is about 10 percent of the previous rate. On high quality sites, basal area of 100-year old western larch forests may approach 300 square feet per acre (69 m^2/ha), while on low quality sites, basal are is about 200 square feet per acre (46

m^2/ha). Basal area increment declines as the site potential is reached (Schmidt and Shearer 1990). Overall, Periodic Annual Increments (PAIs) for gross basal area tend to decrease with increasing age of stands (Cochran and Seidel 1995).

Density

Over 20 years, PAIs for gross basal area generally increased with increasing stand density on stands thinned from below, though the increase was less pronounced with stand densities greater than 50 percent of normal. However, basal area PAIs of the largest trees decreased with increasing stand density. Stands at 25 percent and 50 percent of normal density produced 68 percent and 89 percent, respectively, of the growth basal area PAI compared to fully-stocked stands (Cochran and Seidel 1995). After 30 years, the stand density was related to bole area in a curvilinear fashion (Cochran and Seidel 1999).

After thinning from above and below in a western larch stand in northeastern Oregon, a linear trend of increasing periodic gross annual basal area increment with increasing stand density was found for both thinning methods and across all study periods, though a slight decrease was reported for the highest density level from years five through 20 post-harvest. Among density levels, basal area growth differences were significant ($p < 0.01$), and as the stand aged growth slowed significantly ($p < 0.01$). At the lowest density level, growth increased between the first and second study periods (years 5-10), while it decreased in the other density levels, resulting in a significant ($p < 0.01$) relationship between stand density and growth period (Seidel 1980, 1982, 1984, 1986, 1987).

Equations

Two general growth basal area (GBA) curves are available from Pacific Northwest Region (1987), along with discussion regarding how to determine and use GBA and GBA's relation to stand growth in the Pacific Northwest. Stark (1984) presented a regression equation that adequately predicted five-year basal area growth for western larch 73 percent of the time, though large errors were found on plots with severe root rot, at the edge of western larch's distribution, or on compacted roadbeds. The equation also appears to be less accurate for sites with slow growth.

4. Volume

Western larch volume growth pattern is similar to that for basal area, but it peak volume growth occurs later. Site quality, age, and stocking level are important factors affecting volume yield because of their effects on diameter and height growth. High quality sites with 100-year old western larch forests may yield 11,608 cubic feet per acre (813 m^3/ha), while projections for low quality sites are 4.407 cubic feet per acre (308 m^3/ha) (Table 21). Yields of 7,765 cubic feet per acre are attainable by age 100 on medium quality, fully stocked stands (Schmidt and Shearer 1990). Cochran (1985) reported that cubic volume yields from even-aged western larch stands in Oregon and Washington were comparable to those from Idaho and Montana.

Table 21: Total volume of western larch trees 1.5 cm (0.6 in) and larger in d.b.h. (Schmidt and others 1976)

	Site index at base age 50 years		
Age	12.2 m or 40 ft	18.3 m or 60 ft	24.4 m or 80 ft
yr	*m^3/ha*		
20	[1]*17*	30	45
40	105	184	275
60	191	336	502
80	258	454	[1]*678*
100	308	544	[1]*813*
yr	*ft^2/acre*		
20	[1]*246*	434	648
40	1,494	2,632	3,934
60	2,724	4,801	7,176
80	3,680	6,484	[1]*9,692*
100	4,407	7,765	[1]*11,608*

[1] Values in italics are extrapolated beyond the range of the basic data.

Density

Low board-foot increment usually results when relatively large volumes of overmature trees are left on some cutover areas. This was demonstrated by a 39-year-old partial cutting in a western larch stand originally containing 29,000 board feet per acre. Only slight differences in net annual volume increment were apparent in reserve stands ranging from 1,200 to 11,000 board feet per acre (Division of Silvics 1937, Roe 1948b). Larch made up 52 percent of the original stand volume and 58 percent of the reserve volume in trees 10 inches (25 cm) d.b.h. and larger. Seventy-four percent of the increment in the most lightly stocked stand occurred as ingrowth, principally on species other than western larch, compared with only 30 percent in the most heavily stocked stand. The low net increment rate of 100 board feet per year, produced by the 11,000 board feet residual stands, represents a small return on the heavy volume investment in growing stock. However, by comparison, uncut overmature stands generally show no net growth because growth and mortality are essentially equal (Schmidt and others 1976).

Additional studies conducted at the Coram Experimental Forest and Blue Mountain on the Kootenai National Forest support these results. Three types of cuttings were studied: (1) shelterwood (vigor selection), in which about 50 percent of the volume composed of well-shaped, vigorous trees was reserved; (2) shelterwood (economic selection), in which the larger, financially mature trees were removed leaving the less vigorous codominant and intermediate trees; and (3) seed-tree cutting, in which four to five dominant, vigorous, well-distributed trees per acre plus the nonmerchantable intermediates were left. The shelterwood (vigor selection) produced the greatest net board-foot increment. However, the heavy residual of about 18.8 million board feet in this cutting at Blue Mountain only reached a 10-year periodic annual increment of 103 board feet per acre, or about 0.6 percent annual return on the reserve volume. The five-year periodic annual increment showed annual returns of 0.4 and 0.3 percent at Coram and Blue Mountain, respectively. The shelterwood (economic selection) and seed-tree cuttings at both locations showed lower or even negative annual returns (Schmidt and others 1976).

Such poor growth does not justify leaving residual trees for increment alone; however, these trees may be justified as a seed source, for shade on exposed sites, or for aesthetic reasons. Shelterwood or seed-tree cuttings for natural regeneration that reserve the trees most resistant to windthrow and other damaging agents will minimize the loss of merchantable volume during the regeneration period.

Benson and Schleiter (1980a, 1980c) compared three silvicultural cutting methods (shelterwood, group selection, and clear felling) and four utilization levels (sawlogs only, intensive log, intensive tree, and near complete) of an overmature Douglas-fir-western larch stand at Coram Experimental Forest, Montana. Post-harvest wood volume varied from approximately 40 percent of pre-harvest volume under conventional saw log utilization to less than 20 percent under intensive utilization. Residues also varied with different utilization treatments. Pre- and post-harvest volumes, species and size class, and pre- and post-harvest crown weight data are available in table format (Benson and Schleiter 1980c).

Results of a 30-year thinning study showed that the heaviest thinning level produced the largest trees but lowest volume per acre. Stands at 25, 50, and 70 percent of normal density produced 49, 70, and 87 percent, respectively, of the gross-volume PAI of fully-stocked stands (Cochran and Seidel 1999).

Total gross cubic volume increment increased linearly as stand density increased after thinning from above and below in a western larch stand in northeastern Oregon. Differences in gross cubic volume growth among all stocking levels, except between the two highest stocking levels (levels 4 and 5), were significant ($p < 0.01$). Plots with the highest density had approximately twice as much volume increment as those on the lowest density plots for all periods, though a substantial portion of the growth at high densities was in small trees. Though differences in yield among the four highest density levels were generally small, a trend of increasing net yield (cubic feet) with increasing density was found. Increased diameter growth in low-density plots accounts for all differences in yield. Though gross cubic volume growth was nearly equal in plots thinned from above and those thinned from below, increased mortality from snow and ice in stands thinned from above resulted in substantially lower net growth. Gross cubic increment increased significantly ($p < 0.01$) between the first and second periods then declined slightly during the third and fourth periods. Board foot volume increased significantly ($p < 0.01$) each period, from 80 board feet per acre per year in the first period to 585 board feet per acre per year in the fourth period (Seidel 1980, 1982, 1984, 1986, 1987).

Large areas of uncut overmature larch show no net volume growth because volume lost in mortality approximates growth. Plots in overmature stands on the Coram Experimental Forest disclosed net losses in 10 years of three, four, and six percent in basal area, cubic-foot volume, and board-foot volume, respectively (Schmidt and others 1976).

Models and Equations

Of 20 nonlinear height-d.b.h. models, which can be used to estimate tree volume, that were tested for 16 species, including western larch, the Weibull-type function, the modified logistic function, the Chapman-Richards function, and the Schnute function performed the best (Huang and others 1992). However, after testing performance of three nonlinear functions (Chapman-Richards, modified Weibull, and Gompertz), Gal and Smith (1985) recommend against using nonlinear models for estimating growth and yield.

Van Hooser and Chojnacky (1983) present tables with a variety of information about western larch trees for states in the Rocky Mountain region including growing stock and dry weight statisics. Methods for calculating weight from merchantable volume, as well as for estimating seed weight and volume, are described. Using standing tree measurements, volume of western larch trees and timber selling value can be calculated with Hewlett-Packard 97 and 67 calculator programs (Sachet 1982). Chapman and others (1982) model can be used to estimate average western larch bole volume and green weight for trees less than 12 inches (30 cm) d.b.h. Tables include: mean values of sample tree characteristics used in constructing models; simple correlations among green weight components, cubic foot volume, and selected tree characteristics; total aboveground green weight above stump by diameter and height class; bole (wood + bark) green weight in pounds by diameter above stump and height classes; bole cubic foot volume inside bark by diameter and height classes (Chapman and others 1982).

Plank and Snellgrove (1978) presented a model for estimating volume of western larch and selling value using diameter, height, number of limb-free and defect-free faces in a 16-foot butt, and total tree defect. Faurot (1977) describes methods for estimating total volumes of western larch wood, wood residue, and bark. Testing indicated that this method is more accurate and easier to apply than log grading. Volume tables for western larch trees two to 12 inches (5-30 cm) d.b.h. and 20 to 70 feet tall (above one-foot stump) are also available (Allen and others 1974, 1976). Butt-taper tables for estimating western larch d.b.h. up to 17 feet above ground when a measurement is unavailable (due to deep snow, for example) in order to calculate stand volume are available and are based on data collected in British Columbia (Breadon 1957). Yield, stand, and volume tables, published by Haig (1932), for the western white pine type of northern Idaho included larch as a stand component. Johnson (1955) published western larch volume tables. Terry (1910) published a local yield table from limited data collected on the Kootenai National Forest.

5. Biomass

Timber harvesting practices in larch forests are now utilizing more of the woody biomass formerly left in the woods after logging. Studies in the last decade have characterized this biomass and the environmental consequences of removing biomass from larch forests (USDA 1980). Typically, large volumes of standing live and dead tree biomass are found in old-growth larch forests. For example, of the 7,318 cubic feet per acre (512 m^3/ha) found on a western larch study area on Coram Experimental Forest in western Montana, 55 percent was in standing green trees, 20 percent in standing dead, and 25 percent in down material (Benson and Schleiter 1980b). In addition to tree biomass, shrubs and herbs account for additional biomass (Schmidt 1980b). In terms of weight, the average total biomass was 145 tons per acre (325 t/ha) and was distributed as shown in Table 22 (Schmidt and Shearer 1990).

Though sapwood cross-sectional area estimated crown biomass more accurately than d.b.h. for small trees (d.b.h. 0.2 to 7.7 inches (0.5-19.5 cm)) of some species, for western larch there was no significant difference in the accuracy of the two methods (Snell and Brown 1978). Ter-Mikaelian and Korzukhin (1997) summarize biomass equations for 65 North American tree species, including western larch. Biomass equations for western larch total stem biomass (wood + bark), foliage biomass, and total biomass of branches (wood + bark) are available (Ter-Mikaelian and Korzukhin 1997)

Table 22: Distribution of biomass at Coram Experimental Forest (Schmidt 1980)

Material	**Percent**
Standing green and dead 7.6 cm (3 in) diameter and larger	49
Crown material less than 7.6 cm (3 in) diameter	12
Down wood 7.6 cm (3 in) diameter and larger	11
Down wood less than 7.6 cm (3 in) diameter	3
Shrubs and herbs	2
Litter	1
Duff	22

6. Stand Density

Twenty years after precommercial thinning (to five densities at 10-year intervals) in 1966 of a western larch stand in northeastern Oregon, basal area and total cubic volume growth increased significantly with increasing density. Individual tree volume growth was greater on lower density plots, though overall volume was higher on plots with higher density. Board-foot growth was also greater on low density plots. Stand density did not appear to affect height growth, and mortality was low, except for losses on the two highest densities from an ice storm in 1984 (Seidel 1980, 1982, 1984, 1986).

Western larch's deciduous nature reduces its susceptibility to snow and wind damage in the winter (Wonn 1998, 2001), but it is significantly (significance level 0.05; $p < 0.001$) more susceptible to snow and wind damage if the height-diameter ratio is greater than 80 to 1; above this threshold as many as 99 percent of study trees may incur damage. Spacings greater than 15 feet (4.6 m) may help maintain ratios below the 80 to 1 threshold (Schmidt and Seidel 1998), and spacings greater than 17 feet (5.2 m) appear to increase western larch stability (Wonn 1998, 2001).

In Seidel's (1980, 1982, 1984, 1986) study, windthrow and snow or ice damage caused mortality in areas thinned from above, which resulted in reduced volume growth on those stands. Trees that survived, however, grew well due to the additional growing space. For stands that have not been managed previously, thinning from below is recommended, ideally when trees are 10 to 15 years old and 10 to 15 feet (3-4.5 m) tall, though it is still adavantageous in stands up to 30 years old and 45 feet (18 m) tall. This method should result in increased growth of fewer, fast-growing trees. The greatest diameter growth was found at low densities and the greatest cubic volume growth at high densities, so maximizing both diameter and volume growth cannot be accomplished simultaneously (Seidel 1980, 1982, 1984, 1986).

B. RESOURCE INVENTORY

1. Western larch forest type

Across its range, the western larch forest type occupies nearly three million acres (1.2 million ha), and the species is an important component on millions of acres of other forest types (Schmidt and others 1983). The type occupies approximately 2.3 million acres (930,000 ha) in the United States, about three percent of all timberland in Idaho, Montana, Oregon, and Washington combined (Conner and O'Brien 1995). Approximately 104,000 acres (42,000 ha) in British Columbia, or nine percent of Canadian Inland Mountain West forest lands, are western larch forests (Hegyi and McLellan 1988). Hessburg and others (2000) studied vegetation composition within the interior Columbia River basin and adjacent areas. Overall, changes from early to late seral species occurred, resulting in decreases in western larch in some areas (Table 23).

In the U.S., approximately 81 percent of the western larch resource is under management of public agencies. Of the land in the National Forest system, nearly 131,000 acres (53,000 ha) are unavailable for timber harvest. Most nonreserved (available for harvest) land is on national forests, which accounts for between 80 percent of the western larch land in Idaho and 63 percent in Oregon.

The remainder is divided equally between the forest industry and private landowners, including farmers, ranchers, and Indian reservations (Table 24) (Conner and O'Brien 1995).

Table 23: Historical and current percentage of area of western larch forest cover type of the interior Columbia River basin, by Ecological Reporting Units (Hessburg and others 2000)

Ecological Reporting Unit	Historical (1932-1966) %	Current (1981-1993) %
Blue Mtns	2.6	2.2
Central Idaho Mtns*	0.5	0.3
Columbia Plateau*	1.0	0.1
Lower Clark Fork	0.8	2.6
Northern Cascades	1.0	1.0
Northern Glaciated Mtns*	14.8	11.4
Upper Clark Fork	2.5	3.0
Upper Klamath	0.0	0.1

* indicates mean values are significantly different at $p \leq 0.2$.

Table 24: Total western larch forest type by land class and owner (Conner and O'Brien 1995)

Owner	Reserved (acres)	Nonreserved (acres)	Total (acres)
National Forest	130,962	1,694,006	1,824,968
Other public	---	111,622	111,622
Private	---	200,673	200,673
Forest industry	---	224,280	224,280
TOTAL	130,962	2,230,581	2,361,543

Most nonreserved lands are located in Montana (Table 25), and the ownership in each state is distributed similarly to the overall distribution (Conner and O'Brien 1995). In Montana, the type occupied roughly five percent of nonreserved timberland in 1989. Approximately 162,000 acres (650 ha) are not part of the National Forest System, with various stocking levels (Conner and O'Brien 1993).

Table 25: Nonreserved western larch stands in the U.S., by state (Conner and O'Brien 1995)

State	**Nonreserved western larch (approximate acres)**
Idaho	657,000
Montana	946,000
Oregon	177,000
Washington	511,000

Average forest productivity for all fully-stocked forests in the Interior West is around 50 cubic feet per acre (0.6 m^3/ha). Approximately 930,000 acres (380,000 ha) of western larch forests are capable of producing between 50 and 84 cubic feet (1.4-2.4 m^3) per year. Another 1.1 million acres (450,000 ha), most of which are in Montana and Idaho, have the potential to grow over 85 cubic feet

($2.4\ m^3$) per year. Most of the sites with highest potential productivity (over 85 cubic feet per year) are in Montana and Idaho (Conner and O'Brien 1995).

Table 26: Area of western larch forest type on timberland outside national forests in northwestern Montana in 1989 (Collins and Conner 1991)

Stocking Condition	**Acres of western larch forest type**
Overstocked	15,925
Fully stocked	19,719
Medium to fully stocked	58,762
Poorly stocked	23,639
Mature	43,923
Nonstocked	---
All classes	161,968

Mature and Overmature Stands

Western larch is an important source of saw logs in the Northern Rockies because about 60 percent of the area in which it is a major component is uncut. Most of this area is in western Montana. The vast majority of these virgin forests are overmature; i.e., declining in vigor, health, and soundness. Few of these stands fall in the mature definitions; i.e., fully developed, particularly in height, and with vigor sufficient for full seed production (Schmidt and others 1976). Less than 95,000 acres (38,000 ha), or 18 percent, of the western larch forest type outside national forests, is considered mature (Conner and O'Brien 1995).

Immature stands

In 1970 nearly 40 percent of the western larch type consisted of immature stands. Most of these were established following the large burns of the first half of the twentieth century. Because wildfires occur randomly, pole and sapling stands abound in some areas but are rarely found in others. Although old-growth still predominates, timber harvest and subsequent regeneration are steadily converting the type to younger age classes of better geographic distribution.

Immature larch stands can be divided into three broad categories on the basis of their origin: natural burns, early partial cuttings, or current even-aged management systems. Overly dense stands usually develop following natural burns and even-aged cutting systems; thus, overstocking is a top-priority problem in managing immature larch stands (Schmidt and others 1976).

Nonstocked Lands

Nearly 1.5 million acres (600,000 ha) of nonstocked commercial forestland lie within the Northern Rocky Mountains west of the Continental Divide (determined from tables in Hazard (1963), Pissot and Hanson (1963), and Wilson (1962)). Failure of tree regeneration after severe wildfires, and sometimes after cutting, has been responsible. Approximately half of this nonstocked acreage has the potential for supporting good larch growth (Schmidt and others 1976).

2. Western larch growing stock

At more than 6.0 billion cubic feet (170 million m^3), western larch growing stock accounted for over three percent of the total growing stock in Idaho, Montana, Oregon, and Washington. Thirty-seven percent is found in Montana (Conner and O'Brien 1995) in approximately 842 million trees (Collins and Conner 1991) (Table 27).

Table 27: Distribution of larch growing stock and saw timber volume by state (Conner and O'Brien 1995)

State	**Growing stock (million cubic feet)**	**Sawtimber (million board feet Scribner)**
Idaho	1,422.8	5,322.0
Montana	2,217.4	8,787.0
Oregon	874.0	3,716.6
Washington	1,513.0	5,981.2
TOTAL	6,027.2	23,806.8

National forests have about 63 percent, or 3.8 billion cubic feet of the western larch growing stock. Forest industry lands had approximately 876 million cubic feet (25 million m^3), and other public lands and private lands each have about 500 million cubic feet (14 million m^3) (Conner and O'Brien 1995). On timberland outside of national forests in Montana, western larch makes up the second largest volume of growing stock (Collins and Conner 1991).

Conner and O'Brien (1995) found that over half of western larch's growing stock volume, approximately 3.4 billion cubic feet (96 million m^3), is found in trees smaller than 17.0 inches (43 cm). The volume of western larch trees over 10 inches (25 cm) in diameter has been decreasing slowly, and the volume from trees over 20 inches (50 cm) d.b.h. has declined substantially. In Idaho, most western larch growing stock is in the seedling and sapling age class, while in Montana, the greatest volume is in the potential old growth (greater than 151 years) age class (Table 28) (Losensky 1995).

Table 28: Percent acres by age class for national forest land in northern Idaho and western Montana, 1900 (Losensky 1995)

Age class	Northern Idaho % acres	Western Montana % acres
Non-stocked	20.7	18.2
Seedlings, saplings 1-40	28.5	19.1
Poles 41-60	6.2	5.9
Immature 61-100	9.7	7.3
Mature 101-150	15.0	18.2
Potential old growth 151+	19.9	31.3

Conner and O'Brien (1995) estimated the total growth of western larch in Idaho, Montana, Oregon, and Washington at 134.0 million cubic feet (3.8 million m^3) (Table 29). Western larch growing stock, when mortality is factored in, appears to be increasing approximately 1.7 percent each year. However, changes in growth and mortality rates from wildfire, insects, disease, and other factors can cause large fluctuations in the net growth rate from year to year. In Montana and Idaho, increases of two to three percent of the total inventory are typical (Conner and O'Brien 1995).

Table 29: Average annual western larch growth, mortality, and net change to inventory (Conner and O'Brien 1995)

State	**Total growth**	**Mortality**	**Net growth**	**% change in larch inventory**
	(million cubic feet)			
Idaho	32.0	-6.0	26.0	1.8
Montana	62.7	-15.3	47.4	2.1
Oregon	6.4	-1.7	4.7	0.5
Washington	32.9	-10.5	22.4	1.5
TOTAL	134.0	-33.5	100.5	1.7

Numerous other resources with western larch growing stock statistics are available, including Bassett and Oswald (1983), Benson and others (1987), and Wilson and Van Hooser (1993),

3. Western larch harvest

The increase in western larch harvest since World War II has been attributed to increased timber demands accompanied by decreased availability of other species and increased accessibility of old-growth (Schmidt and others 1976).

Based on Keegan and others' (1995b) data, approximately 460 million board feet, Scribner, or 2.30 million cubic meters of western larch are harvested and processed each year (Table 30). Approximately 65 percent is processed into lumber, roughly one-third is used for plywood, and the remaining harvest is used for house logs, poles and posts, shakes and shingles, fuelwood, or pulp.

The species is most important in Montana, where it provided approximately 15 percent of the total 237.3 million feet (83 million m) of timber processed in 1988 (Keegan and others 1990; McLain and others 1992). Table 29 shows the distribution of western larch timber use by product in 1988 (McLain and others 1992).

Table 30: Annual utilization of western larch (Keegan and others 1995b)

	Million board feet, Scribner	Million cubic meters
Sawmills	300	1.5
Plywood plants	150	0.75
Other	10	0.05
TOTAL	460	2.30

Table 31: Average annual volume of western larch processed by state or province, 1986-1990 (Keegan and others 1995b)

	Million board feet, scribner	Million cubic meters
British Columbia	110	0.55
Idaho	90	0.45
Montana	200	1.00
Eastern Washington	30	0.15
Eastern Oregon	30	0.15
TOTAL	460	2.30

Table 32: Timber use in Montana, 1988 (McLain and others 1992)

Product	**Volume harvested (1000 cubic feet)**
Sawlogs	17,759
Veneer logs	15,055
Pulp	255
House logs	56
TOTAL*	33,125

*does not add up do to rounding

4. Economics of western larch

Though Koch (1923) reported that western larch in national forests was "for the most part worth less than nothing," Larsen's (1916) prediction that western larch would "have a future value" has been realized. The forest products industry is important to the economy of the Northwest region, and some of the most timber dependent regions rely heavily on western larch (Keegan and others 1995b). Western larch accounts for 20 percent of the timber processed in Montana counties that depend upon the forest products industry for 25 to 50 percent of the economic base (Keegan and others 1990). Western larch primary processing accounts for between 4,000 and 8,000 jobs annually, and in total western larch processing and related activities provide approximately 8,000 to 12,000 jobs and more than $300 million in labor income annually. From 1986-1990, the lumber and residue sectors generated the most sales value from western larch primary products (Table 33) (Keegan and others 1995b).

Table 33: Average annual employment from harvesting and processing western larch, 1986-1990 (Keegan and others 1995b)

Activity	**Number of workers**
Logging	1,400
Sawmills	1,000
Plywood plants	800
Residue-related products	500
Other manufacturing and private sector land management	300
TOTAL	4,000

Table 34: Average annual sales value of the primary products manufactured from western larch from 1986 through 1990 (Keegan and others 1995b)

Activity	**Millions of 1990 dollars**
Lumber	150
Plywood	75
Residue sector (pulp, paper, particleboard, fiberboard, etc.)	130
Other	10
TOTAL	365

C. PHYSICAL AND MECHANICAL PROPERTIES

1. Description

Western larch heartwood is yellowish to reddish brown. The sapwood is whitish to pale straw brown in color and narrow, usually less than one inch (2.5 cm) wide (Balactinecz 1986; Forest Products Laboratory 1951, 1963; Lowery 1984; Perem and others 1981). The species' bark to wood ratio is 0.10 (Van Hooser and Chojnacky 1983)

Typically growth rings are narrow (15-60 per inch (6-24/cm)), uniform, and distinct with a noticeable separation between light-colored earlywood and darker latewood zones, the latter of which occupies about 20 to 25 percent of the ring (Balactinecz 1986; Forest Products Laboratory 1951, 1963; Lowery 1984). Butt logs of western larch frequently contain large amounts of shake, or separation between the grain of annual rings (Lowery 1984). The wood often looks and feels oily, and resin exudations may be present, but it has no pronounced odor or taste (Forest Products Laboratroy 1963; Lowery 1984; Perem and others 1981). Western larch wood is exceptionally straight-grained with a coarse texture (Balactinecz 1986; Forest Products Laboratory 1951; Lowery 1984; Perem and others 1981), and boles may be up to 175 feet (53 m) long and clear for much of the length

(Forest Products Laboratory 1951). It is fairly heavy (40 pounds per square foot ($640 kg/m^3$)) in the air-dry condition (Balactinecz 1986), and is similar to Douglas-fir in mechanical properties and density, so the two species are often marketed together (Forest Products Laboratory 1951).

All larch species have heartwood with high density, strength, and decay resistance (Abaimov and others 2002), and western larch is among the hardest of the softwoods. Its density at 12 percent moisture content is approximately 36 pounds per cubic foot ($576 kg/m^3$) (Lowery 1984). Western larch trees in the two-inch (5-cm) diameter class weigh approximately 10 pounds (4.5 kg) per tree ovendry, and those in the four-inch (10-cm) class were 50 pounds (23 kg) per tree (Van Hooser and Chojnacky 1983). It is strong in bending and endwise compression, stiff, and moderately high in shock resistance. (Lowery 1984)

Specific gravity of western larch wood ranged from 0.38 to 0.54, with an average of 0.48 reported by the Forest Service (1965b) and Lowery (1984). Specific gravity in western larch tends to decrease with increasing height. This trend may be explained by the general pattern of increasing specific gravity with age, which is due to increased proportions and density of latewood (Okkonen and others 1972).

Compared to other softwood and hardwood species, western larch has high screw- and nail-holding capacities (Lowery 1984; Williams and Morris 1998). Williams and Morris (1998) also presented results of studies of machining properties of western larch and 14 other soft- and hardwood species.

Table 35: Average clear-wood strength values for western larch (Panshin and de Zeewu 1970)

Trait	**Green condition**	**Air-dry condition**
Relative density (specific gravity), basic	0.55 (green)	0.58
Relative density, oven-dry		0.64 (oven dry)
Shrinkage, radial* (%)	5.1	-
Shrinkage, tangential (%)	8.9	-
Shrinkage, volumetric (%)	14.0	830
Modulus of rupture (psi)	8700	15,500
Modulus of elasticity (1000 psi)	1650	2080
Compression parallel to grain, crushing strength maximum (psi)	4420	8842
Shear strength (psi)	920	1340
Compression perpendicular to grain, fiber stress at proportion limit (psi)	520	1060
Tension perpendicular to grain (psi)	420	520

*Shrinkage values are for green to oven-dry based on dimensions when green

Kelsey and others (1979) tested combustion of nine Rocky Mountain conifer species, including western larch. Overall, bark, twigs, and foliage produced more heat than ovendry wood of the same volume, and within species bark and foliage had the highest and lowest heating values, respectively. Though there is probably little industrial importance, significant differences at the five-percent level were found between the higher heating values of western larch and other species tested for bark, twigs, and foliage. Grand fir bark values were not significantly different, nor were the twig values of western white pine, lodgepole pine, or Douglas-fir. Higher heating values for western larch are in Table 36.

Table 36: Average higher heating values for western larch and the average of nine species (Kelsey and others 1979)

Part of tree	Western larch combustion value (Btu/lb)	9-species combustion value (Btu/lb)
Wood	8370	8721
Bark	9162	9461
Twigs	9247	9233
Foliage	8703	9315

Western larch wood is relatively difficult to work, but it finishes nicely. Penetration of the heartwood with preservatives is rather difficult (Lowery 1984; Perem and others 1981). It glues easily but does not hold paint well. Moderate radial, tangential, and volumetric shrinkage values for western larch of 5.1 percent, 8.9 percent, and 14.0 percent, respectively, can be expected (Table 34). Though warping and checking may present some problems, overall it seasons well (Panshin and de Zeewu 1970). Reports on treatment of western larch wood are available (Wayman 1950; 1952; Whyland 1950).

Western larch wood is moderately durable (Lowery 1984; Perem and others 1981). In accelerated decay tests of western larch, western redcedar, Douglas-fir, and lodgepole pine, western larch was generally most resistant. There were differences, though minor, in the degree of radial versus tangential resistance. Also, specific gravity of western larch was related to resistance, though this pattern did not occur with the other species (Englerth and Scheffer 1954).

D. PRODUCTS

Western larch forests are valued for a wide range of uses. This large, often dominant tree, with delicate foliage that changes from light green in spring and summer to a brilliant gold in the fall adds to the aesthetics of the landscapes in which they occur (Keegan and others 1995b; Lowery 1984; Schmidt and Shearer 1990; Thompson 1995). A wide variety of birds and animals find protection and food in these forests.

Limited harvest of western larch characterized the early twentieth century because logs frequently did not have a market value high enough to pay the costs (Davis and Klehm 1939). During and after World War II, western larch timber became more valued because of booming lumber markets that required greater utilization of species other than western white pine and ponderosa pine (Hutchison 1948). Now, western larch is one of the most important timber-producing species in the western United States and western Canada. It has the densest wood of the northwestern conifers and is also very durable and moderately decay-resistant. Its high heating value makes it one of the best fuel woods in the region (Arno and Hammerly 1977; Flora of North America Association 2000; Hosie 1969; Schmidt and Shearer 1990; USDA NRCS 2002). Western larch is used interchangeably with Douglas-fir for construction lumber and plywood (Kotok 1973; Whitford and Craig 1918). However, plywood, poles, and interior paneling are usually sold as larch (Lowery 1984). The wood is also used commercially for construction framing, railroad ties, pilings, mine timbers, interior and exterior finishing, and pulp, and burned snags are often used to make shakes (Abaimov and others 2002; Arno and Hammerly 1977; Benson and others 1987; Flora of North America Association 2000; Hosie 1969; Keegan and others 1995; Lowery 1984; Perem and others 1981; Schmidt and Shearer 1990; Schmidt and others 1983; USDA NRCS 2002). High sugar content of western larch makes it undesirable for concrete forms because the sugars react chemically with the concrete (Schmidt and others 1976).

1. Lumber

Before 1940 western larch was considered a weed species, and the annual lumber production fluctuated around 200 million board feet. However, after 1945, lumber production increased steadily, and by 1984, was reported to average more than 500 million board feet per year (Lowery 1984). The main product of western larch is construction lumber. Due to the wood's strength, it is often used for timbers, planks, boards, and other dimension products. Western larch boards are commonly used for interior finishing, flooring, water tanks, boxes, crates, pallets, railway cars, and electrical machinery. For most of these purposes it is used interchangeably with Douglas-fir (Lowery 1984). In addition, crossarms for electrical or communication wires were made from western larch at one time (Jacobi 1950). Preliminary research indicated that impression finger jointing with western larch for production of high-strength end joints may be feasible (Strickler 1967). The use of small-diameter trees, including western larch, for lumber and veneer production is becoming increasingly economically and technologically viable. Willits and others (1997) reported that volume and grade recoveries of small trees (8-14 inches (20-36 cm) d.b.h.) 60 to 90 years old were similar to those of larger trees, and that advances in technology have helped increase the volume of lumber that can be used from small trees (Willits and others 1997).

Of 682 western larch logs from Montana six percent had defects that decreased the yield of wood products, and ring shake was more detrimental than the other defects (Cahill and Cegelka 1989). Drying processes may affect the quality of western larch wood. Overall, drying caused degrading of 50 percent of all lodgepole pine and western larch studs, and one to 1.5 percent greater losses occurred in western larch than in lodgpole pine. Warp and surface checks were responsible for more degrade than other defects. Higher drying temperatures caused more surface checking, while conventional drying temperatures caused more warp. Longer drying periods may help improve the quality of western larch products (Kimball and Lowery 1967b). Grading rules for western larch are available. At 22 percent moisture content, the minimum allowable density for western larch is 30 pounds per cubic foot (480 kg/m^3). At one percent moisture content the density changes 0.10 pounds per cubic foot (1.6 kg/m^3) (Great Britain, Forest Products Research Laboratory 1941).

2. Plywood and Veneer

Western larch is considered an excellent species for plywood (Anderson 1948), and it has been used for both rotary and sliced veneers since the 1950s (Anderson 1954; Forest Products Laboratory 1951). The plywood industry in the Northern Rockies uses substantial western larch; for example, in Montana western larch supplied about half of the wood used in the manufacture of plywood in 1962 (Wilson 1964a), and about 40 percent in 1966 (Setzer and Wilson 1970). Most western larch plywood and veneer is used by the construction industry (Lowery 1984).

Western larch's growth habit often produces substantial knot-free material, and small logs up to 16 inches (41 cm) in diameter may be nearly free of knots to a three or four inch (7-10 cm) core. Forty to 50 percent clear veneer yields are possible from western larch peeler logs from virgin stands (Anderson 1954). Schowalter (1949) reported that western larch logs, unlike the other species studied, were entirely free of compression wood. It sands and glues well, and results in a high-quality finish. The contrast between the sapwood and heartwood creates an attractive pattern, and its grain does not show through paint. Its strength is similar to that of coastal Douglas-fir (Mueller 1951a).

Ring shake, which is undesirable for rotary cutting, occurs in some western larch logs but can usually be culled out before cutting. Knots were generally found at diameters under 12 inches (30 cm), and most western larch logs resulted in substantial clear veneer. Due to ring shake, some western larch did not yield suitable veneer. Other defects included rot, heart check, compression wood, pitch streak, and frost cracks. None caused substantial veneer loss. Almost all of the usable veneer was heartwood (Forest Products Laboratory 1951).

Green heartwood of western larch averages 50 to 60 percent moisture content, and as high as 150 percent. Drying 0.0625-inch (0.16-cm) veneer produced less brittle veneer than that dried to two to five percent. Western larch veneer dries flat and uniform, and tangential shrinkage averaged 6.05 percent when dried to two to five percent final moisture content (Forest Products Laboratory 1951; Mueller 1951a; Schowalter 1949). Because western larch peeler logs sometimes have streaks (up to 2.5 inches (6.35 cm) wide and 18 inches (46 cm) long) of heavy moisture content, distortion in the dry product may result. However, this material can easily be clipped after drying (Anderson 1954). Average tangential shrinkage of western larch veneer is 6.05 percent (Mueller 1951a).

Heating western larch bolts to approximately 150° Fahrenheit (66° C) before cutting appears to yield the most smooth, tight veneer with the fewest checks (Anderson 1954; Mueller 1951a; Forest Products Laboratory 1951; Northern Rocky Mountain Forest and Range Experiment Station 1948). Significantly more end checks occurred in bolts heated above 160° Fahrenheit (71° C). Veneer cut to 0.125 inch (0.32 cm) at 140° Fahrenheit (60° C) was less tight and smooth than that at 150° Fahrenheit (66° C), but 0.0625-inch (0.16-cm) unheated veneer was acceptable. Heating schedules for western larch veneer bolts and lathe settings for cutting western larch veneer are available (Forest Products Laboratory 1951; Mueller 1951a). When cut cold, veneer thicknesses up to 0.125 inch (0.32 cm) are reasonably free of defects (Anderson 1954; Schowalter 1949), though knots may nick the knife (Schowalter 1949).

Western larch can generally be glued with a variety of resin glues under a variety of conditions (Mueller 1951a). Homogenous boards prepared from western larch bark and bonded with 10 percent resin appear to be similar to particleboard in terms of their water-absorption values, though those at 7.5 percent resin had higher values (Maloney 1973). Ripley (1961) reported that western larch veneer dried in oil or gas driers may not glue as well as that from steam driers.

High concentrations (up to 15 or 20 percent by weight) of galactan found in western larch logs leave a "whitish, crystalline exudation" on dried veneer (Anderson 1954; Forest Products Laboratory 1951), the exact amount of which depends on drying temperatures and which part of the tree the material is from (Carstensen 1961). Veneers cut from the sapwood or the outer heartwood have the highest galactan concentrations (Carstensen 1961; Forest Products Laboratory 1951), and higher drying temperatures may increase the amount extracted and deposited on the veneer (Carstensen 1961). This material can be sanded off, though tends to gum up sanders faster than other species (Anderson 1954; Forest Products Laboratory 1951). While western larch with light to moderate galactan concentration adheres adequately using standard Douglas-fir glue formulas and pressing schedules for interior and exterior use (Carstensen 1961; Forest Products Laboratory 1951), western larch veneer with heavy galactan concentrations is not suitable for exterior purposes. Adding two to three percent more caustic to the glue mix and extending minimum assembly times may help offset the effects of galactan concentrations (Carstensen 1961).

Western larch is sometimes added to Portland cement, which is used as a particle-board binder (Hofstrand and others 1984). They found that, of the nine northern Idaho species tested, western larch negatively affected the setting of wood-cement-water mixtures the most. Inorganic and organic compounds significantly accelerated hydration of western larch cement mixtures (Zhengtian and Moslemi 1985). Continuous water extraction of western larch particles before being added to the cement mixture also mitigated the deleterious effects. Even small amounts of water-soluble wood extractives can dramatically affect hardening of wood-cement composites (Zhengtian and Moslemi 1986). Moslemi and others (1983) found that chemical additives, calcium chloride in particular, may strengthen bond formation in wood-cement composites made with western larch.

Details of the slicing, rotary peeling, drying, and gluing behavior of western larch veneers are available. Specifications for western larch peeler logs are available with regard to grain, knots, heart check, rot, pitch pockets and shake, size, and scaling (Anderson 1948). The National Institute of Standards and Technology (1996) describes standards for construction and industrial plywood, including that made from western larch.

3. Poles

Larch makes excellent utility poles because of its long length, exceptional form, and great strength (Herrington 1955). Wilson (1963) reported that larch made up

11 percent of all utility poles produced in the Northern Region between 1947 and 1962. Nearly 60 percent of these were between 40 and 55 feet (12-17 m) long, but only 18 percent of those from lodgepole pine, the preferred pole material in Montana, were in this range. In Montana, Idaho, and northeastern Washington, an estimated 1.4 million poles were produced between 1947 and 1962 (Lowery 1984). Dimensions and specification for wood poles, including western larch are available (American National Standards Institute 1972). Incising is a necessary prerequisite to obtain adequate preserative retention. (Lowery 1984)

The shallow depth of sapwood (Lassen and Okkonen 1969) in western larch makes it difficult to obtain penetration of preservatives to a sufficient depth in some trees to meet industry specifications. Heartwood is many times harder to penetrate with preservatives than sapwood, thus poles must possess sapwood that is as deep or deeper than the desired depth of preservative treatment. Ordinarily, the industry requires no less than a 0.5-inch (1.3-cm) preservative ring in treated poles. Therefore, the finished peeled pole must be surrounded by at least a 0.5-inch (1.3-cm) layer of sapwood. To obtain this layer of sapwood, some companies specify a minimum 0.75-inch (1.9-cm) sapwood depth in trees cut for utility poles. Then after peeling, even with some loss, a 0.5-inch (1.3-cm) layer of sapwood will remain (Schmidt and others 1976).

Sapwood depth is related to growth rate or tree vigor. Thus, trees growing at average or better rates normally possess enough sapwood to qualify them for transmission poles. Factors that slow down tree growth, such as overstocking, diseases, and insects, reduce the depth of the sapwood ring sufficiently to prevent effective preservative treatment. Conversely, cultural measures that improve tree growth enhance the trees' value for transmission poles (Schmidt and others 1976).

Spiral grain commonly occurs in western larch, as well as in other species, and affects pole stability after installation. Studies of larch spirality (Lowery 1966; Lowery and Erickson 1967; Northern Rocky Mountain Forest and Range Experiment Station 1953; Wellner and Lowery 1967) point out several important factors:

1. Nearly all larch trees (96 percent) exhibit some spirality pattern, but fewer than 10 percent are spiraled enough to cause poles to be degraded.
2. Spiral grain is a major cause of pole twisting.
3. Poles twist in the same direction as spirality.
4. Left (clockwise)-spiral grain is more severe, occurs two to three times as frequently, and causes more severe pole twisting than right (counterclockwise)-spiral grain.

5. Right-spiraled poles usually contain left-spiral grain inside the pole that counterbalances the tendency toward right-hand twist, but left-spiraled poles contain no such counterbalancing force.
6. Poles with straight or right-spiral grain are stronger than those with left-spiral grain.
7. Long-crowned, rapid-growing trees in open stands tend to have grain that spirals more severely and frequently to the left than trees in closed stands.
8. The position of a tree on the slope has no apparent effect on direction or severity of spiral grain.
9. During dry periods, poles tend to twist in the direction of spiral and untwist somewhat during wet periods.

Laboratory tests on the bending strength of spiral-grained Douglas-fir and western larch indicate that right-spiraled poles are nearly as strong as straight-grained, but that left-spiraled poles are weaker than either. The average ratios of bending strengths of sprial-grained to straight-grained poles of Douglas-fir and western larch, respectively: right spiral 0.91 and 0.88; left spiral 0.46 and 0.59. Analysis of available twist data so far neither confirmed nor refuted the hypothesis that direction of spirality is associated wtih changes in growth rate. (Intermountain Forest and Range Experiment Station 1963b).

Transmission pole classes developed by the American National Standards Institute (1972) are based on minimum acceptable circumferences at the top and at six feet (1.8 m) from the butt. The minimum circumference of the latter varies with the length of the pole (poles are usually measured in five-foot (1.5-m) classes). Although 15 pole classes are recognized, the commercial poles fall mainly in the first 12 classes. The pole classes are designed chiefly to define poles of sufficient strength for specific use requirements, and therefore they define pole quality.

Pole lengths available from average dominant and codominant trees vary according to tree diameter, stand age, and site index. On site index 60, an 80-year-old stand will yield poles ranging from 40 to 60 feet (12-18 m) depending on the tree diameter. An 18-inch (46-cm) tree in this situation will yield a 55-foot (16.8-m) pole if it does not have disqualifying crook, sweep, or spiral grain.

Although pole length is related to site quality, there appears to be no significant relationship between pole class and site index. Data from a western larch pole study indicated that the best timber sites did not have a higher proportion of class one western larch poles than the poorer sites. However, the true relationships here may be clouded because the pole trees sampled on the poorer sites were slightly older than those sampled on the better sites.

Pole class changes significantly with age and reflects the change in form as the tree grows older. A significantly greater proportion of the higher pole classes (1 through 4) occurs in certain ecological habitat types. Western larch trees found in the grand fir-Oregon boxwood, western hemlock-Oregon boxwood, and

Douglas-fir-ninebark types provide by far the largest proportion of the better pole classes (1 through 4). Furthermore, trees found in these three habitat types also show the largest proportion of class 1 poles, ranging from a low of 6.5 percent to a high of 12 percent.

Drying western larch poles at temperatures between 180 and 200° Fahrenheit (82-93° C) for two to three days resulted in an adequate final moisture content for subsequent treatment with preservatives, though the high temperatures caused a slight reduction in strength of the poles. Tangential penetration of pentachlorophenol (PCP) preservative into western larch heartwood ranged from 0.125 inch (0.3175 cm) to 0.25 inch (0.635 cm). After drying and treatment with PCP, the total length of western larch checks per foot was less than that of lodgepole pine though in general western larch had longer, wider, and deeper checks (table 37) (Lowery and Rassmussen 1963).

Table 37: Comparison of two pole drying trials (Lowery and Rassmussen 1963)

Drying temperature (F)	180	230
Drying time (hours)	72	40.5
Initial average moisture content (%)	70.3	69.1
Final average moisture content (%)	30.5	31.0
Average moisture loss (%)	39.8	38.7
Surface checks per foot (#)	141.6	126.5

A small sample of creosote-treated Douglas-fir and western larch transmission poles in Alberta, Canada, were evaluated for decay after 25 years of service. Fifteen years after installation, no poles showed signs of decay. After 25 years, however, 62.5 percent had decay associated with checks, mechanical damage, and unknown factors, indicating that butt-treated poles of Douglas-fir and western larch may be less desirable than those of other species (Cooper and Ross 1977). On Saipan, Mariana Islands, PCP-treated western larch began decay before being attacked by termites. Severe damage to the outer 0.8 to 1.2 inches (2-3 cm) of western larch poles was also caused by personnel climbing poles with spikes, while Douglas-fir suffered only minor damage (DeGroot 1988). Shortle and others (1978) described a method of determining the degree of decay in utility poles, including western larch poles, by measuring electrical resistance.

4. Mine Timbers

Because of its hardness and resistance to splintering, western larch has been used for mine-shaft guides. High-speed underground mine hoists run along these guides to lift personnel and ore. Mine timbers have also been made from western larch (Lowery 1984). Western larch will carry maximum loads as heavy as those of Douglas-fir. However, it is less desirable because it does not "cry" under excess pressure as Douglas-fir does. It is also heavier, making mine timbers of western larch harder to handle (Rapraeger 1942).

5. Pulp and Paper

Sawmill and plywood plant residues of western larch can be chipped and used for making pulp and paper (Lowery 1984). Myers and others (1997) found that submerchantable logs and small trees and tops of western larch are suitable for pulping. However, due to its low kraft pulp yield, western larch is not an ideal source for this material. Western larch small trees and tops yielded thermomechanical pulp and paper with low property values (Myers and others 1997). Before being processed into paper, it may be necessary to treat western larch chips with water in order to extract the arabinogalactan (Lowery 1984).

6. Shingles

In a study of shingles, including those made from western larch, in Oregon, Miller (1986) found that western larch shingles are not likely to decay within five years. After 10 years, untreated western larch shingles appeared less prone to decay than untreated shingles and less likely to suffer serious damage due to decay than those made from western hemlock or sugar pine (Miller 1991).

4. Extractives

The two primary extractives that can be isolated from western larch are arabinogalactan and dihydroquercetin. Giwa and Swan (1975) found these in concentrations of 11.1 percent and 0.5 percent, respectively. Other extractives isolated from western larch include: resin acids, larixol and larixyl acetate, pinocembrin, isolariciresinol, and free L-arabinose and secoisolariciresinol (Giwa and Swan 1975).

Arabinogalactan

The best domestic source of arabinogalactan, a water-soluble natural gum (Ettling and Adams 1968), is from the wood of western larch (Nazareth and others 1961). High yields of water-soluble arabinogalactan can be extracted from western larch (Côté and others 1966; Ponder and Richards 1997a), though extraction and purification of arabinogalactan from western larch have historically presented obstacles to extensive commercial use. However, more economical and efficient processes have been developed, and continued technological improvements in extraction and purification of western larch will increase its practicality for commercial use (Ponder and Richards 1997a).

Arabinogalactan is used for offset lithography and in the food, pharmaceutical, paint, ink, and other industries (Schmidt and others 1976). It is used as an industrial emulsifier (Lowery 1984) and shows promise for increased use as a commercial polymer (Christian and others 1998; Ponder and Richards 1997c).

The pharmaceutical industry uses it as a pill or tablet binder (Lowery 1984), with similar effectiveness as acacia (Nazareth 1961b). Groman and Gou (1997) reported that arabinogalactan may be a useful drug carrier for deliver to the liver. Ponder and Richards (1997a) reported that the presence of acidic units as components of western larch arabinogalactan, which might influence cell wall interactions and other biological activities, may affect the substance's usefulness for medical purposes. Prescott and others (1995a) present a method for isolating arabinogalactan fragments with lower molecular weights, which may be more useful for targeted drug delivery.

Baking powder can be produced from muric acid, a derivative of galactose. The remaining sugars can be converted to ethyl alcohol (Kressman 1915; Northern Rocky Mountain Forest and Range Experiment Station 1946a; Sherrard 1922), and fodder yeast and molasses for stock feed (Northern Rocky Mountain Forest and Range Experiment Station 1946a).

Arabinogalactan from western larch is currently being used in a variety of products marketed by Larex, Inc. for human health purposes including a prebiotic fiber, immune-stimulating dietary supplements, dietary fiber products for humans and animals, and as an ingredient in personal care products. In addition, is is marketed as an ink additive and for other biomedical and pharmaceutical applications (Larex 2000).

Western larch wood contains from four to 23 percent arabinogalactan on a drywood basis (Austin 1954) with the highest concentrations in the lateral roots and decreasing up the tree (Table 38) (Mitchell and Ritter 1951, 1953, 1956; Northern Rocky Mountain Forest and Range Experiment Station 1946a). Arabinogalactan concentration was minimal or absent in sapwood, and was heavy on the border of heartwood and sapwood. Larger concentrations were found in early wood than late wood, and normal wood had more than compression wood (Borgin 1949; Côté and others 1966). Because waste butt logs, sometimes left in the woods, are high in sugar content, they are the most desirable source of the gum (Austin 1954).

Table 38: Galactan content of western larch (Mitchell and Ritter 1956)

Source	**Galactan Content**
Lateral roots of virgin trees	~11-23 percent
Slabwood from virgin growth	
Butt	14
Middle	4.2-10
Top	~5
Fire-killed virgin trees	
Butt	9-16
Middle	6.6-12.1
Top	6.6-7.8
Thinnings from second growth stand	
Butt	3.8-5.3
Middle	2.1-3.5
Top	2.2-3.1

Arabinogalactan in western larch is found outside the cell wall, indicating that it is not a structural wood polysaccharide and that it does not affect the strength properties of western larch wood (Côté and others 1967). Since other deciduous conifers such as ginko and baldcypress have minimal water-soluble extracts, it is unlikely that arabinogalactan presence is related to western larch's deciduous nature (Côté and others 1967). Gierlinger and others (2002) found that Fourier transform near infrared spectroscopy (FT-NIR) is a useful non-destructive method for determining heartwood extractive content of western larch.

The chemistry of arabinogalactan has been studied extensively since the early twentieth century, and detailed reports are available (Bouveng and Lindberg 1956; Côté and others 1967; Ekman 1961; Ekman and Douglas 1962; Eremeeva and Bykova 1992; Manley-Harris 1997; Ponder 1998; Ponder and Richards 1997a, 1997b, 1997c, Prescott and others 1995a, 1997). Arabinogalactan can be separated into two components with different molecular weights and compositions (Bouveng 1959; Bouveng and Lindberg 1958). Methylation and hydrolysis of western larch arabinogalactan yields a combination of arabinoses, galactoses, disaccharides, and trisaccharides, the amounts of which vary (Bouveng 1959a, 1959b; Bouveng and Lindberg 1956, 1958). Polysaccharides from other larch species have similar compositions (Bouveng 1959a; Jones and Reid 1963).

Dihydroquercetin

Dihydroquercetin, a 3-hydroxy-flavanone also known as taxifolin, is found in the heartwood, sapwood, and needles of western larch (Barton and Gardner 1958; Gardner and Barton 1960; Hergert and Goldschmid 1958). Hergert and Goldschmid (1958) suggested that the substance is synthesized in needles and transported to other parts of the tree. Sasya and others (1970) reported a sapwood concentration of 1.6 percent and heartwood concentration of 1.8 percent for western larch. Its concentration in heartwood generally decreases toward the pith and varies substantially within and between trees (Barton and Gardner 1958; Gardner and Barton 1960; Sasya and others 1970).

Dihydroquercetin has potential for use in medicinals due to its flavonoid character and its easy conversion to quercetin. As an antioxidant is is useful for preventing rancidity in fats, oils, and dairy products. Other characteristics that may be important industrially include "inhibition of calcium base sulfite pulping, the ability to corrode digester steel in the presence of kraft alkaline pulping liquors, and fungicidal activity" (Gardner and Barton 1960; Sasya and others 1970). Dihydroquercetin content can be assessed using a rapid colorimetric method (Barton and Gardner 1958; Gardner and Barton 1960).

Essential oils

Oleoresin from western larch is used to produce turpentine and other products (Mahood 1921; Schmidt and others 1976). The oleoresin has the consistency of honey, is light amber in color, and has an agreeable odor. It contains 16-percent volatile pinene and limonene (Mahood 1921).

Resin cells and passages secrete resin in western larch. Seven days after wounding western larch sapling stems, monoterpene cyclase activity was generally higher in wounded stems than in unwounded stems, though the difference was not significant. Table 39 shows the results of gas chromatography of western larch whole stem sections seven days after wounding, when the monoterpene content of western larch was 3.44 ± 0.64 mg (g fresh wt)$^{-1}$ (Lewinsohn and others 1991).

Table 39: Monoterpene composition of western larch stem sections (Lewinsohn and others 1991)

Component	**Percent composition**
α-Pinene	37.3
Camphene	0.5
β-Pinene	39.9
Sabinene	3.2
3-Carene	15.0
α -Phellandrene	0.1
Myrcene	1.1
α -Terpinene	0.1
Limonene	1.0
β-Phellandrene	0.9
γ-Terpinene	0.5
ρ-Cymene	0.1
Terpinolene	0.5
Oxygenated derivatives	<1

Krasnoboyarova and others (1985) reported that levels of essential oils from one-year shoots and two-year shoots of three larch species, including western larch, were different from those of the needles, and that levels also varied with species. Rudloff (1987) found that yields of volatile terpenes from western larch twigs were generally higher than those from needles. Twigs were also easier to transport without loss of the oils.

5. Other Uses

The bark of western larch is able to efficiently remove Chromium (Cr(VI)) from dilute aqueous solutions, making it a "promising alternative for the treatment of wastewaters containing Cr(VI)" (Aoyama and Tsuda 2002).

E. IMPORTANCE TO LIVESTOCK AND WILDLIFE

Western larch forests provide food and cover for a wide range of fauna. Rodents eat seeds and seedlings, birds forage for insects and nest in western larch, and squirrels often cut and cache cones. Deer, elk, and moose browse larch, though probably only as a last resort, and black bears forage on sugars that are concentrated in the sap layer in the spring (Schmidt and others 1976).

Several studies have investigated the importance of western larch forests to woodpeckers. McClelland (1995) found that pileated woodpeckers, a sensitive species dependent on old-growth western larch forests, used 17 times more western larch trees than Douglas-fir even though Douglas-fir trees were five times more abundant. Hadfield and Magelsson (2000) reported all western larch trees in their five-year postburn study showed signs of woodpecker foraging, and most feeding occurred in first year after tree death. After stand replacing fires in conifer forests of the northern Rocky Mountains, Hutto (n.d.) found evidence of woodpecker foraging on 64 percent of western larch trees larger than 3.9 inches (10 cm) d.b.h. compared with 81 percent of ponderosa pine, 48 percent of Douglas-fir, 2.3 percent of Engelmann spruce, and 0.2 percent of lodgepole pine.

1. Palatability and nutritional value

Western larch appears to be unpalatable to most big game animals, but it is eaten as emergency food (Schmidt and Shearer 1990; Schmidt and others 1976). Its seeds are palatable to small birds and mammals, although larger seeds are preferred (Shearer and Halvorson 1967). Larch needles provide a major source of food to several species of grouse (Arno and Hammerly 1977).

Nutrient values for western larch needles, twigs, and other tree parts have been reported from two sites in western Montana (Stark 1983). Whole tree values have also been published (Stark 1982). Western larch needles at two locations in eastern Washington contained 2.0 percent and 1.7 percent nitrogen, respectively (Gower and Richards 1990). Green needles from Lubrecht Experimental Forest in western Montana had a mean ash content of 5.8 percent with a range of 3.47 to 8.16 percent, and those from Coram Experimental Forest, Montana, had mean ash content of 5.3 percent with a range of 4.9 to 8.9 percent (Table 40).

Table 40: Nutrient values for western larch needles at two sites in Montana (Stark 1983)

	Lubrecht mean	**Lubrecht range**	**Coram mean**	**Coram range**
Calcium (μg/g)	3,031	2,000-4,800	2,213	1,980-2,390
Copper (μg/g)	8.3	5.0-15.2	15.5	10.7-35.2
Iron (μg/g)	86.8	41-173	126	109-218
Potassium (μg/g)	6,405	2,800-9,760	4,958	4,390-5,388
Magnesium (μg/g)	1,098	692-1,592	1,083	1,005-1,113
Manganese (μg/g)	216	81-405	181	160-239
Nitrogen (μg/g)	13,518	9,730-15,540	23,320	17,920-28,923
Sodium (μg/g)	61.4	24.4-123.0	56	45-125
Phosphorus (μg/g)	2,343	1,678-3,189	2,960	1,894-3,269
Zinc (μg/g)	15.8	6.0-35.6	24.6	21.1-27.7

2. Cover value

Woodpeckers and other cavity nesters utilize western larch. Around its decaying interior, a dead western larch tree retains a protective layer of sapwood, which provides nesting, roosting, and feeding opportunities. Flying squirrels (*Glaucomys sabrinus*), woodpeckers, owls, and various songbirds nest in rotting western larch cavities. Snags are used by osprey (*Pandion haliaetus*), bald eagles *(Haliaeetus leucocephalus)*, and Canada geese (*Branta canadensis*) for nesting (Arno and Hammerly 1977), and raptors may nest in brooms of trees infected with dwarf mistletoe (Bull and others 1997). Up to 10 percent of black bear (*Ursus americanus*) dens have been found in hollow standing western larch trees (Bull and others 1996).

Birds

Western larch provides nesting, roosting, and foraging habitat for a variety of bird species. Snags, in particular, provide important habitat for cavity nesters and should be considered when planning long-term wildlife management strategies (Bull and others 1980, 1990; McClelland 1995).

In northwest Montana, 54 percent of active pileated woodpecker (*Dryocopus pileatus*) nests were found in large broken-top western larch snags, a highly significant preference. Of the roost sites found, 53 percent were in western larch, though there were 3.6 times as many Douglas-fir trees in the area. These woodpeckers appear to prefer to nest in dense forests with old-growth western larch or ponderosa pine (McClelland 1979).

In western larch forests of northwestern Montana, 53 percent of pileated woodpecker nests and 65 percent of the roosts found were in western larch. Most nest and roost sites were in snags with broken tops (McClelland and McClelland 1999). Another study found that 53 of 54 pileated woodpecker nests were in western larch, 72 percent of which were snags, and the mean d.b.h. was 31.5 inches (80 cm) (McClelland 1995). In western larch forests of northwestern Montana, cavity-nesting birds preferred western larch for nests over Douglas-fir even though Douglas-fir was more abundant. Nests were found in live and dead trees, and large diameter or broken-topped trees were preferred (McClelland and others 1979). Cavity nesters, especially woodpeckers preferred western larch, ponderosa pine, balsam poplar, paper birch, or aspen nest trees that had heartwood decay at Coram Experimental Forest, Montana, and the highest density and greatest diversity of cavity nesters were found in forests that had some western larch old-growth (McClelland 1980). In Montana, McClelland and

Frissell (1975) found 46 of 83 active birds' nests in western larch, 36 of which had broken tops.

After artificial girdling or cutting of tops to induce decay, western larch declined quickly and became suitable for avian foraging before nine other tree species studied (Hallett and others 2001). Samples from 20 western larch woodpecker nest cavities in northeastern Oregon revealed that all nest cavities were associated with decayed wood (Parks and others 1996). Heartwood decay softens western larch's relatively hard wood, making excavation easier. In more mature forests, heartwood decay is more common, which may partially explain woodpeckers regular use of old-growth stands with western larch (McClelland and McClelland 1999). Woodpeckers' preference for western larch may also partially be due to the fact that western larch sapwood decays slowly, maintaining a protective barrier around decaying heartwood (McClelland 1995).

Results indicated that western larch over 25 inches (64 cm) d.b.h. with broken tops and taller than 50 feet (15 m), especially those with one or more existing holes, are the most valuable snags to leave for cavity nesters (McClelland and Frissel 1975). Pileated woodpeckers in Oregon fed on deadwood of snags, logs, and natural stumps in dense forests with concentrations of snags (Bull and Meslow 1977). Bull and others (1980) recommend managing for 1.58 snags per acre (3.9/ha) in order to maintain woodpecker populations at 70 percent of potential.

Size is also an important factor in tree selection. Average diameter of nests trees in Montana was 27 inches (69 cm), height was 95 feet (29 m), and nest height was 71 feet (22 m) (McClelland and Frissel 1975). And in 1979, McClelland reported that in northwest Montana, nest tree average height was 92 feet (28 m), d.b.h. averaged 30 inches (75 cm), and the average height of the nest hole was 49.9 feet (15.2 m). Roost sites had similar measurements, most likely because roosts were old nests (McClelland 1979).

Pileated woodpeckers in northeastern Oregon were found nesting in snags of western larch and ponderosa pine over 23 inches (58 cm) d.b.h. (Bull and Meslow 1977). A study of winter use of post-fire habitat in northeastern Washington found that woodpeckers preferentially foraged on western larch, ponderosa pine, and Douglas-fir nine to 14.5 inches (23-37 cm) d.b.h. (Kreisel and Stein 1999).

In old-growth forests of northwestern Montana, red-naped sapsuckers (*Sphyrapicus nuchalis*) preferred western larch and paper birch for nest sites over other available species. The average diameter of western larch nest trees was 27 inches (69 cm). Red-breasted nuthatches (*Sitta canadensis*) nested in old sapsucker nest holes. Sapsuckers selected western larch with heartwood decay (87 percent) and they excavated in the upper bole, where bark is thinner (McClelland and McClelland 2000). Of 31 red-naped sapsucker nests studied at Coram Experimental Forest, Montana, 35.5 percent were in western larch, and 71 percent of the trees had indications that woodpeckers had previously nested or foraged there (Tobalske 1992).

Live western larch with dwarf mistletoe provide natural stick nest platforms for the great gray owl (*Strix nebulosa*). The owls preferred unlogged, mature stands where grand fir, Douglas-fir, and western larch were present (Bull and Henjum 1990). Mistletoe brooms also provide nest habitat for great horned owls (*Bubo virginiansis*), and Vaux's swifts (*Chaetura vauxi*) nest and roost in hollow trees of western larch (Bull and others 1996).

Other Animals

In northeastern Oregon, 13 percent of American marten (*Martes americana*) nests were found in rust and dwarf mistletoe brooms, and 31 percent of these were in western larch, Douglas-fir, lodgepole pine, and ponderosa pine. Of the dwarf mistletoe brooms used as rest sites, 47 percent were in western larch, more than the other species. Most broomed trees were alive, and summer use by marten was greater (68 percent) than in winter (32 percent) (Parks and Bull 1997). In another study, 10 percent of American marten rest sites during the snow-free months were in hollow logs, the average diameter of and length of which were 24.8 inches (63 cm) and 65.6 feet (20 m), respectively. Of these, 23 percent were western larch (Bull and others 1996). Hollow trees also provide roosting cover for denning martens (Bull and others 1996).

In southern British Columbia, bats (*Eptesicus fuscus, Lasionycteris noctivagans, Myotis evotis and M. volans*) preferred roosts in western white pine, and to a lesser degree in ponderosa pine and western larch over other species (Vonhof and Barklay 1996).

CHAPTER FIVE

PROFESSIONAL PAPER REPORT

A. PROJECT BACKGROUND

In the fall of 2001, I began working as a technical writer for the Fire Effects Information System (FEIS), a project of the Fire Sciences Laboratory of the Forest Service. During that time, I reviewed literature and wrote summaries emphasizing the fire ecology of plant species for publication on the FEIS website (http://www.fs.fed.us/database/feis/). The outline for these summaries included the following topics: taxonomy, distribution and occurrence, botanical and ecological characteristics, fire ecology, fire effects, fire case studies, management considerations, and value and use of the species. One of the species I was assigned was western larch.

Western larch is one of the most ecologically and economically important, aesthetically pleasing, and biologically unique trees in its range, which includes upper Columbia River drainage as well as a few areas east of the Continental Divide in Montana and Alberta. It is the most fire resistant tree in the region and one of the most important timber species. Its unusual deciduous habit and brilliant fall color make it a tree that piques nearly everyone's interest at some time or another. For all of these reasons, western larch is a frequently studied species, and it is important that this information be available to researchers, managers, academics, and the public.

The Ecology and Silviculture of Western Larch Forests by Wyman C. Schmidt, Raymond C. Shearer, and Arthur L. Roe was published in 1976 as a U.S.D.A. Forest Service technical bulletin. This publication was a comprehensive summary of the current research about western larch forests. Since 1976 much additional research has been published. Also the authors of the original text—who are the experts on western larch—have already retired or will do so this year. Forest Service personnel in the Washington Office, Rocky Mountain Station Headquarters, and the Ecology Research Work Unit located in Missoula at the Forestry Sciences Laboratory (FSL) determined that it was time to revise the outdated publication. They asked FEIS to recommend someone to help with literature reviews; since I was already researching western larch for FEIS, it made sense for me to work on both projects.

I was assigned four complete chapters as well as portions of one chapter of the revised publication including the following topics: western larch ecology, including phenology and genetics; the influence of biological factors such as disease, insects, and animals; growth and yield; physical and mechanical properties; and products. For each section, FSL provided a complete bibliography; with approximately 1200 references relevant to my assigned sections. In addition, I was asked to include relevant information from my FEIS summary in my FSL report. This paper is a compilation of the information from both the FEIS and FSL bibliographies, and eventually will be incorporated into the revision of the Schmidt and others' 1976 publication.

Like the FEIS website, *The Ecology and Silviculture of Western Larch Forests* is primarily intended for use by land managers and professionals. However, since both are available to the public, I hoped to write in a way that would not only provide technical details, but also be intellectually accessible to interested laypeople.

B. PROCESS

Though my work on this project, I have learned as much about how to more efficiently and effectively review scientific literature as I did about western larch. As I mentioned above, I had approximately 1200 references to review, so I had to develop a system. I hope that the following description of the process that I used will be helpful to others who are doing similar projects. The process that I use to review literature can be broken down into five steps. I call them rank, review, record, rearrange, and revise.

The first step was to rank the articles, or to figure out which ones I actually needed to review. Some articles were already cited in the 1976 publication, so I skipped these under the assumption that any pertinent information had been cited in the original publication. There were also a handful of articles that I had already reviewed for FEIS. If they had anything to do with fire, I knew that I had already looked them over carefully, so I skipped them. For the ones that weren't about fire, I would take skim them quickly for additional relevant information that I didn't use in my FEIS write up. The rest, I had to review. I also considered the date of the article at this point, too. If it was older than 1970, I assumed that it was available for review and inclusion in the 1976 bulletin, but I usually still skimmed them. However, if it was published later, I'd take a closer look.

The second step was to review publications. I was fortunate in that I did not have to go to the library stacks for the literature. FEIS had a library of their materials, and the FSL had a library of the articles about western larch. If I had needed to find each article in the library, I would not have been able to cover nearly as much material. But even so, with so much literature to review, there wasn't time to read them all in full. In fact, I rarely read a whole article. Instead, I developed a system for "reading" the articles that allowed me to find the information I needed in the least amount of time.

I'd start by looking at the title—often that would give me a pretty good idea of how relevant the article was. Then I'd read the abstract. If western larch wasn't mentioned in the title or abstract, I knew it wasn't the focus of the study, but there still might be some useful tidbit. So I'd read the conclusions, if there were any, or I'd skim the discussion. If there wasn't any mention of western larch by this point, then I'd just skim the article looking for "western larch" or "*Larix occidentalis*." I was surprised at how good I got at reading very little, but still always finding the word larch. Sometimes I would doubt myself and wonder if I was just flipping through the pages aimlessly. But my eyes would often stop on the word "large" which is pretty close to larch, so this helped give me some confidence. Basically, I just had to trust that I would catch it, and I think I usually did.

Most articles did mention western larch in the abstract, conclusions, or discussion. Sometimes it would just be a little tidbit that I could use, so I'd record that and move on. If the article had an emphasis on western larch, however, I'd look it over a little more closely. I'd go to the results to find the data to back up the more general findings, and to look for useful tables and graphs. Then I'd read the introduction, which usually provides some background on why the study was important. And finally, the methods section was the usually the last part I'd read. I'd look for where the study happened and when, as well as other tidbits that would help explain how broadly the findings can be applied. For example, were the results relevant to the field, or just nurseries? Do they apply to all of western larch's range or only certain regions? And so on.

Third, I had to take notes, or record. I used two different note-taking systems throughout the process; I'll call them the "outline system" and the "database system." The first system I used was the outline system. When I was writing for FEIS, I had to use FrontPage software for all my writing, and errors frequently occur after cutting and pasting from other programs into FrontPage.

So I became accustomed to taking notes directly into the outline in FrontPage, then revisiting each section later to synthesize and smooth over the material. I started off using this system for this literature review too, except I used Word. I created a rough outline and then typed notes, with citations, directly into the appropriate sections.

About half way through the literature, I started using different software called ProCite. This program is a bibliography database that allows you to enter bibliographic information about each publication as well as an abstract and notes. In this case, it was especially useful because nearly all of the publications had already been entered into the database, and in some cases, the abstract had also been entered. If I would have had to enter each citation myself, I'm not sure this system would have been as efficient for this project. When using the ProCite system, I entered the abstract and any additional relevant notes into the database, one article at a time. Each record was assigned a call number according to which section the publication best fit, so this made it easy to sort and find specific records. Later, I cut and paste the notes and/or abstract from the database to the outline in my Word document.

The database system was very helpful for me, and I often returned to the entries to track down isolated pieces of information, such as a date or location, that had been lost in the rearrange and revise process. I recommend using the database system if more than one person is working with the same literature, if one person plans to use the same literature for more than one project, or if the research takes place over a long period of time. Another situation in which a database system may be useful is with a large bibliography to manage. The program can generate a bibliography relatively easily and convert it to different styles depending on specific needs. However, because entering the bibliographic information is quite time consuming, and cutting and pasting also takes a while, I would not recommend it for small, one-time projects, especially if only one person is doing the research.

The fourth and fifth steps—rearrange and revise—happen nearly simultaneously. And actually, it goes more like rearrange, revise, rearrange, revise, and so on. Ultimately the process is more than five steps, and could go on infinitely. Section by section, I revised my notes by combining repetitive information, deleting unnecessary material, and re-wording the text. Then I looked for common themes, created subheadings, and moved information around accordingly. Again, I'd revise the material, and rearrange it some more, et cetera. In my case, this process continued until I ran out of time. And since this material will be incorporated as part of another, more thorough, publication on western larch, it will undergo further revisions and rearranging at a later date.

C. RECOMMENDATIONS

During the considerable amount of time I have spent with this project, reading the literature about western larch and attempting to synthesize the available information somewhat concisely, I have thought about suggestions for consideration in the revision of Schmidt and others' 1976 technical bulletin.

First, some of the language that is used in the literature seems heavily slanted toward timber production. For example, it seems that the terms "immature," "mature," and "overmature" refer to a stand's timber production qualities rather than other qualities of the stand or trees within. These terms apparently have widely understood meanings, but to a reader who is not aware of these definitions, it can be confusing. It would be valuable to consider characterizing stands, when possible, by some other standard, such as their reproductive status, age, stage in succession, or density. A related suggestion is to ensure that goals or objectives are specified when referring to management practices, especially when a certain practice is "recommended" or considered the "best." This will help the reader by clarifying whether a certain practice is suitable for wildlife management, timber production, aesthetics, or other values.

Second, much of the available literature on western larch, especially older literature, has a timber production emphasis. Given the progression of public lands management toward including additional uses such as recreation, wildlife management, and other purposes, it may be appropriate to include a discussion about the implications of the available research for management of these other uses. I hope that the end result will be a publication that can be used to inform a variety of needs including not only timber production, but also conservation and other interests.

D. OTHER THOUGHTS

I went into this project with a goal of trying to make the final product something that would be more fun to read than your average scientific paper. But I realized that it's a lot easier said than done, especially with so much information that needed to be included. For this project it was important to cite as many sources as possible, to include data where it was relevant, and to keep the language objective.

As I tried to make the writing more interesting, I realized that these types of things are the things that, unless used pretty sparingly, make it less fun to read. Things that people read for fun give you a few juicy statistics and then summarize the rest of it using non-scientific terms and speaking more generally. And the really good stuff mixes in some stuff that makes the information more personal. None of these things were tools I could really use for this document, and that's fine. I realized that I want to write something about western larch that will engage a non-scientific audience then it's probably going to have to be a whole different project with a slightly less objective intent. And that leads me to my last thought I wanted to share.

Though I'm sure it's not a new thought, I realized through working on this project—both while reading other people's stuff and trying to write my own—that no matter how hard we try to be objective, it's impossible to be entirely objective. If a person wrote it—and I assume there is a real person behind the names on everyone of the papers I read—then their experiences and perspectives and backgrounds and worldviews will be in the paper, even if they aren't explicitly stated.

For example, sometimes I would read something like, "The such and such method is the best practice"—it was never worded exactly like that, but I ran across things like this periodically. And sometimes—though rarely—it wouldn't be explicitly stated what it was the "best" for. Is it best for timber production, best for wildlife, best for aesthetics, etc? I could usually figure it out by the context, and a phrase or two would probably have answered my questions, but a critique of writing style is not what I'm after here. What I'm getting at is that I realized just how important it is, whether we're reading or writing about science, that we are honest with ourselves about the fact that we are, at least partially, subjective creatures.

I'm not suggesting that we write this into our papers: *I am a subjective creature.* And I'm not criticizing scientific writing and its attempts to be objective. I think it's critical that we have a medium like scientific writing that forces us to think about and talk about things as objectively as possible. It's the best way we have to remove personal biases. But I also think it's good to keep in mind its limitations. We can't remove people from the scientific writing equation—at least I hope not—so we can't ever entirely remove subjectivity and biases from it either.

I tried to keep this in mind as I was writing, but my biases are still there. Along the way, I had to make a lot of decisions about what information to include and whether to include something in detail or as an aside. I tried to be as honest as possible about making these decisions based on how relevant the information was to western larch, and then trust the reader to know that I'm just one interpreter of the information out there. If someone else had done the same project, the end product would likely look a little different. And fortunately, there are other people out there doing similar things, so we can compare different interpretations.

Maybe other people have had different experiences in their scientific training, but mine emphasized the importance of looking at how a study was done, what they found, and what it means. My thought is—and I'm sure it's not original—that we also ask who did the study, who does she work for, what is his training, and also who published the study and where is this group coming from? The answers to these questions shouldn't necessarily be used to judge the accuracy or validity of a study, but they give us perspective. And whether we're scientists, managers, activists, interested citizens, or some combination, that perspective is useful and necessary.

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Appendix

Scientific and common names of plant species mentioned

Scientific name	Common name
Abies amabilis	Pacific silver fir
Abies concolor	white fir
Abies grandis	grand fir
Abies lasiocarpa	subalpine fir
Amelanchier alnifolia	Saskatoon serviceberry
Aralia nudicaulis	wild sarsaparilla
Arceuthobium americanum	lodgepole pine dwarf mistletoe
Arceuthobium campylopodum	western dwarf mistletoe
Arceuthobium douglasii	Douglas-fir dwarf mistletoe
Arceuthobium laricis	larch dwarf mistletoe
Arceuthobium tsugense	hemlock dwarf mistletoe
Arctostaphylos uva-ursi	bearberry
Berberis nervosa	dwarf Oregon-grape
Betula papyrifera	paper birch
Calamagrostis rubescens	pinegrass
Clintonia uniflora	queencup beadlily
Erythronium grandiflorum	glacier lily
Gaylussacia dumosa	dwarf huckleberry
Ginkgo biloba	ginkgo
Juniperus scopulorum	Rocky Mountain juniper
Larix decidua	European larch
Larix kaempferi	Japanese larch
Larix laricina	tamarack
Larix lyallii	alpine larch
Larix occidentalis	western larch
Larix gmellini	Dahurian larch
Linnaea borealis	twinflower
Menziesia ferruginea	menziesia
Paxistima myrsinites	Oregon boxwood
Physocarpus malvaceus	ninebark
Picea engelmannii	Engelmann spruce

Picea sitchensis	sitka spruce
Pinus albicaulis	whitebark pine
Pinus contorta	lodgepole pine
Pinus contorta var. *latifolia*	Rocky Mountain lodgepole pine
Pinus jeffreyi	Jeffrey pine
Pinus lambertiana	sugar pine
Pinus monticola	western white pine
Pinus ponderosa	ponderosa pine
Pinus ponderosa var. *scopulorum*	interior ponderosa pine
Pinus sylvestris	scots pine
Populus balsamifera	balsam poplar
Populus spp.	aspen
Populus tremuloides	quaking aspen
Pseudotsuga menziesii	Douglas-fir
Pseudotsuga menziesii var. *glauca*	Rocky Mountain Douglas-fir
Quercus garryana	Oregon white oak
Rubus parviflorus	thimbleberry
Sequoia sempervirens	redwood
Symphoricarpos	snowberry
Symphoricarpos albus	common snowberry
Taxodium distichum	baldcypress
Thuja plicata	western redcedar
Tsuga heterophylla	western hemlock
Tsuga mertensiana	mountain hemlock
Vaccinium caespitosum	dwarf huckleberry
Vaccinium membranaceum	big huckleberry
Vaccinium scoparium	grouse whortleberry
Xerophyllum tenax	beargrass