Mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.): an annotated bibliography

D. G. W. Edwards and M. D. Meagher

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Contents

Abstract

This bibliography on mountain hemlock contains 209 new references to be added to those listed in the Franklin (1962) bibliography on this species. The oldest citation dates to 1867, while the most-recent was published in 1994. The Franklin (1962) compilation is referenced, but the individual listings are not included herein. Articles are listed alphabetically by authors, and all have been abstracted.

Résumé

Cet ouvrage bibliographique concernant la pruche subalpine répertorie 209 ouvrages de référence qui ne figurent pas dans le Franklin (1962) du U.S. Forest Service concernant cette essence. L'ouvrage le plus ancien remonte à 1867 tandis que le plus récent date de 1994. Le compilation de 1962 est citée en référence mais les ouvrages qui y figurent ne sont pas répertoriés. Les articles sont classés par ordre alphabétique d'auteur et chacun fait l'objet d'un résumé.

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Dover Publications (New York) kindly gave permission to reproduce the illustration of mountain hemlock cones used on the cover. The original drawing appeared in "Forest trees of the Pacific Slope," by George B. Sudworth, U.S. Dep. Agr., Forest Service, 1908, which was reprinted by Dover in 1967.

Preface

Mountain hemlock (*Tsuga mertensiana* [Bong.] Carr.) is recognized as an important subalpine species that, in complexes with other species, serves as a protective cover for watersheds, as a wildlife habitat - especially for deer summer range on Vancouver Island (Harestad 1980) - and as a major long-term component in the subalpine ecosystem, sometimes attaining more than 800 years (Means 1990).

Most abundant between 1000 and 1500 m in coastal areas of British Columbia and Alaska, the species extends from 61° 25'N at sea level (Viereck and Little 1972), to southeastern British Columbia, northern Idaho, northwestern Montana, and the Cascade mountains, reaching elevations of 2750 to 3050 m in the Sierra Nevada (Parsons 1972). Outlying populations have been recorded as far south as central California, 36° 38'N (Parsons 1972). Although distribution maps show mountain hemlock in an apparently narrow band along the coastline of the Pacific Northwest, it is actually widely spread in longitude, from 152°W in Alaska to 114°W in Montana. Populations in the interior of British Columbia, Idaho and Montana are disjunct from those on the coast.

With current timber harvesting in British Columbia extending further into subalpine elevations, it is important to understand the range, diversity, and regeneration potential of high-montane species for more effective management and conservation of the resource. No gene conservation plan or tree improvement program for this species exists. Recently, mountain hemlock was included in a world list of "threatened" species (Farjon *et al.* 1993), primarily in relation to the disjunct nature of its distribution.

It has been proposed that *Tsuga*, as a genus, is closely related to *Picea*, and that mountain hemlock is more similar to spruce than to other hemlocks (Owens and Blake 1983; Taylor 1972. The reader should also refer to Campo-Duplan and Gaussen 1948, Duffield 1950, Flous 1936, and Vabre-Durrieu 1954, all cited in Franklin 1962). Populations of individuals morphologically intermediate between western hemlock and mountain hemlock have been given hybrid status (*Tsuga* x *jeffreyi* (Henry) Henry) (Dahms and Franklin 1965; Duffield 1950), but there is little evidence that true hybrids occur. The issue is summarized in Means (1990), but little is really known about genetic variation within the species.

A research study to assess some aspects of genetic diversity of mountain hemlock in British Columbia commenced in 1992. As background to this work, a literature search was performed and the results of this search are presented here as an updated bibliography. An earlier compilation by J.F. Franklin (1962) that contained 290 citations is cited here, although its individual citations have not been included since it is a United States Government publication accessible through most libraries. Users of this updated listing, which consists mainly of articles published since 1963 (i.e., after Franklin's compilation) should remember that there is a substantial number of other citations in that publication. However, Franklin's list did not include some earlier literature that is included here.

In compiling this list, the authors relied heavily on Forestry Abstracts, Biological Abstracts, plus Literature Cited lists of other published papers. In most instances, the abstracts presented in this compilation are those appearing in the journal, or provided by the abstracting service. Where mountain hemlock was not the main emphasis of the publication, the abstract has been edited to focus on this species. Additionally, approximately 35 percent of the abstracts, especially for the earlier literature not cited by Franklin (1962), were written by the present compilers. Articles are listed alphabetically by author, and we have included a subject index that is based on terms derived from the title and subject matter of the article. Periodical title abbreviations follow the system of "Serial Sources for the BIOSIS Data Base", BIOSIS, Philadelphia, PA.

A number of possible citations, notably in tree books and gardening or landscaping works, have been excluded, since they offer no additional scientific information on the species. However, the compilers would appreciate having additional technical references to mountain hemlock brought to their attention.

December 1994

Bibliography

1 AGEE, J.K. 1983. Fuel weights of understorey-grown conifers in southern Oregon. Can. J. For. Res. 13: 648-656.

Fuel weight by size classes for five understorey conifers (*Abies concolor, A. magnifica* var. *shastensis, Pinus ponderosa, P. contorta* var. *murrayana* and *Tsuga mertensiana*) was estimated using regression equations. Trees ranged from 0.1 to 3 m tall and were selected from 'open' and 'dense' overstorey classes. Live and dead fuels from each tree were segregated into five diameter classes. Regressions for foliage and total fuel weight are presented using as independent variables groundline diam, total ht, diam^2 x ht and ba. Coefficients of determination (r^2) were high, exceeding 95% for total weight in every case, but tended to decrease as diameter size class increased. Relative shade tolerance of the five species is estimated by comparing open-growth and dense-growth foliage weight ratios for each species.

2 AGEE, J.K.; FINNEY, M.; DE GOUVENAIN, R. 1990. Forest fire history of Desolation Peak, Washington. Can. J. For. Res. 20: 350-356.

A 400-yr fire history was developed for the seven forest community types defined within a 3500-ha area in the vicinity of Desolation Peak (North Cascades). Fire-return intervals were hypothesized to be shorter than typical for coastal forest types, such as those dominated by western hemlock (*Tsuga heterophylla*) and Pacific silver fir (*Abies amabilis*), and longer than typical for interior forest types, such as ponderosa pine (*Pinus ponderosa*). The average natural fire rotation was 100 yr; this varied by a factor of 2 by century and by topographic aspect. Forest types typical of coastal regions, such as Douglas-fir (*Pseudotsuga menziesii*)/western hemlock and mountain hemlock (*Tsuga mertensiana*)/Pacific silver fir, had mean fire-return intervals (108-137 yr) much lower than in other W. Washington areas. The most interior forest type, ponderosa pine/Douglas-fir, had a greater mean fire-return interval (52 yr) than reported for similar forest types east of the Cascades. It is concluded that fire has influenced structural and landscape diversity on Desolation Peak significantly, and that future active disturbance by fire may be important in the maintenance of such diversity in the future.

3 AGEE, J.K.; KERTIS, J. 1987. Forest types of the North Cascades National Park Service Complex. Can. J. Bot. 65: 1520-1530.

A forest cover type classification based on 425 plots resulted in eight forest cover types, including a mountain hemlock type, each with a variety of plant associations. Cover types were integrated into a geographic information system used to create a cover type map that was 85% accurate. The forest cover types of the park complex are unique, not so much for within-community diversity as for the close juxtaposition of cover types with interior and coastal climatic influences.

4 AGEE, J.K.; SMITH, L. 1984. Subalpine tree re-establishment after fire in the Olympic Mountains, Washington. Ecology 65: 810-819.

Fire behaviour was observed in recent fires, and the effects of climate and seed source on reforestation were evaluated on burns 3, 55 and 88 yr old in order to identify the most flammable subalpine plant communities, the persistence of fire-created meadows and the predictability of the reforestation process. All three sites supported *Abies lasiocarpa/Tsuga mertensiana* forest before the fires. Tree regeneration was only partially correlated with time since disturbance, but was higher during normal-to-wet growing seasons than during dry growing seasons, and was also higher near the edge of the fire than further from seed sources. *T. mertensiana* established well in wet periods; *A. lasiocarpa, Pseudotsuga menziesii* and *Pinus monticola* established well in normal periods. Regeneration on the older burns suggests that tree establishment on these sites is largely unpredictable because future climate cannot be predicted.

5 ALDEN, J.N. 1984. Genetic methods in forest inventory. Pages 211-219 in V.J. LaBau and C.L. Kerr (editors). Inventorying forest and other vegetation of the high latitude and high altitude regions. Proc. Int. Symp., Fairbanks, Alaska, USA, July, 1984. Soc. Am. For., Bethesda, MD, USA.

Annual increment and wood volume or mass per tree species and unit area are traits of practical interest in forest inventory. Such traits vary geographically because of differences in site productivity and in inherent differences in the populations occupying the sites. Genetic surveys attempt to separate the contributions of site and inherent productivity. Inherent productivity of different populations is evaluated in common environments and, if possible, is correlated with habitat. Local populations can be delineated from traits that are under strong genetic control. Two biochemical traits used for this task are the enzymes (isozymes) separated by gel electrophoresis and quantity of volatile monoterpenes determined by gas-liquid chromatography. Information from genetic surveys in forest inventories will enable us to define the genetic resources of commercial species while undisturbed wild populations still exist. This task includes publishing maps of the precise geographic distribution and stocking for each species, identifying the extent and nature of differences between local populations, and improving techniques for detecting genetic variation.

6 ANDERSON, R.S. 1990. Holocene forest development and palaeoclimates within the central Sierra Nevada, California. J. Ecol. 78: 470-489.

Pollen and plant macrofossils in sediments from three high-altitude lakes were used to determine vegetation changes since 12 500 BP. Trees were established by about 10 000 BP, with more open structure and more montane chaparral shrubs than the present day; drier conditions are inferred. By 6000 BP, precipitation had increased, with an increase in subalpine conifers – mainly mountain hemlock (*Tsuga mertensiana*) and red fir (*Abies magnifica*). Upper altitudinal limits of many subalpine conifers began to fall about 2500 BP, coincident with the beginning of Neoglacial cooling.

7 ANON. 1963. Characteristics of Alaska woods. U.S. For. Serv., For. Prod. Lab., Res. Pap. FPL-1, 64 p.

Essentially a compilation of information relating to the characteristics, distribution, and utilization of *Tsuga heterophylla, T. mertensiana, Picea sitchensis, P. glauca, Thuja plicata, Chamaecyparis nootkatensis, Pinus contorta, Populus trichocarpa, P. tremuloides, P. balsamifera,* and *Betula papyrifera* in Alaska. The mechanical characteristics, seasoning data, and preservative treatments of various of these species are discussed, and tables summarizing strength properties, pulp processes and yields, and drying schedules are included.

8 ARCHER, A.C. 1964. Some synecological problems in the alpine zone of Garibaldi Park. Pages 5-18 *in* V.J. Krajina. Ecology of the Forests of the Pacific Northwest, 1963 Prog. Rep., Dep. Biol. and Bot., Univ. B.C., Vancouver, Appendix A.

Mountain hemlock, sub-alpine fir and yellow cedar form krummholz communities near treeline. Mountain hemlock seems to follow yellow cedar and subalpine fir in krummholz invasion. Snow cover and duration are the major factors influencing vegetation establishment, type and succession. Plants requiring high soil base-exchange capacity are succeeded by more acidophilous species as leaching under plant cover acidifies soils.

9 ARNOTT, J.T. 1979. Effect of light intensity during extended photoperiod on growth of *Abies amabilis, Tsuga mertensiana, Picea glauca,* and *Picea engelmannii* seedlings in container nurseries. Can. J. For. Res. 9: 82-89.

Tsuga mertensiana and other conifer seedlings were grown in an outdoor container nursery using one high-pressure sodium vapour lamp to provide a 24-h photoperiod. Eight intensities were arranged, viz., 220, 80, 40, 20, 12, 8, 5, and 0 lux. Extending the photoperiod and increasing the light intensity had a significant positive effect on the length and weight of seedling shoots and delayed terminal bud set. Root-growth response to these treatments was negative, although the differences were rarely significant. Seedlings grown under a light intensity of 220 lux were the largest. The minimal intensity required to produce seedling shoot lengths which were significantly larger than the controls was in the range of 20-8 lux.

10 ARNOTT, J.T. 1985. Photoperiod control of container seedlings. Pages 9-13 *in* T.D. Landis (compiler). Proc. West. For. Nurs. Counc./Intermt. Nurseryman's Assoc. Comb. Mtg., Coeur d'Alene, Idaho, Aug. 1984. U.S. For. Serv., Gen. Tech. Rep. INT-185.

The use of extended photoperiods to grow *Tsuga mertensiana* and other conifer seedlings in container nurseries is reviewed. Factors investigated were: the critical maximal and minimal light intensities required by the seedlings when using photoperiod lighting; comparisons of natural daylength extension and cyclic lighting (interruption of darkness); the effect of photoperiod lighting failure on tree seedling growth; and the influence that photoperiod lighting has on the tree seedling growth in the following year.

11 ARNOTT, J.T.; MACEY, D.E. 1985. Effect of supplemental light intensity on white spruce, Engelmann spruce, and mountain hemlock seedlings grown under an extended photoperiod. Can. J. For. Res. 15(2): 295-300.

Tsuga mertensiana and other conifer seedlings were grown in an unheated shelterhouse container nursery, with a high-pressure sodium vapor lamp providing a 19-h photoperiod and light intensities of 1600, 800, 400, 200, and 100 lux. The control seedlings received natural daylight and photoperiod. No terminal buds were formed at the 1600 lux intensity for *T. mertensiana* and none of the light intensities effectively prevented bud set in the other species. Higher light intensities produced greater mean stem-unit lengths and delayed the terminal bud set. The greatest *T. mertensiana* shoot lengths were grown under light intensities of 400 lux. There were no significant differences in seedling shoot weight, root weight, and root-collar diameter among the five light intensities. Light intensity had little effect on the second year's growth.

12 BAE, H.; HANSEN, E.M.; STRAUSS, S.H. 1993. Restriction fragment length polymorphisms demonstrate single origin of infection centers in *Phellinus weirii*. Can. J. Bot. 72: 440-447.

Restriction fragment length polymorphism (RFLP) markers were used to isolate genetic variation in *Phellinus weirii*. Six isolates (including three from mountain hemlock) of the Douglas-fir and cedar-type biological species were surveyed with 12 restriction enzymes and 20 random, mitochondrial, and nuclear-ribosomal gene probes. Isolates from the two host species, Douglas-fir and mountain hemlock, showed few RFLP differences, but strong differences were found with all tests on a "cedar" biological type collected from western redcedar. Initiation of infection centres, and subsequent vegetative or basidiospore-initiated immigration, appear to be rare events producing infection centres that differ in numerous probe combinations, but which are genetically uniform within.

13 BAILEY, W.H. 1964. Revegetation of the 1914-1915 devastated area of Lassen volcanic national park (U.S.A.). Diss. Abstr. 24: 3068.

The eruptions of 1914-15 destroyed all vegetation except a few trees on an area of 1.25 x 4 miles on the east slope of the mountain. Pre-disturbance meadows are being taken over by trees and shrubs, largely because of mudflow influence. Where lodgepole pine had become established, white fir and white or Jeffrey pine appear to be replacing it. Coppice growth from surviving mountain hemlock and red fir stumps forms part of the high-elevation vegetation from which stands may extend. There is a definite zonation pattern in the central part of the devastated area, starting with lodgepole pine at 6250 ft (1906 m) and ending with red fir and lodgepole pine at 7500-8000 ft (2287-2440 m). New growth along the N and S margins is variable, the greatest width occurring at 7500-7700 ft (2287-2348 m) along the S boundary, where white fir, red fir, white pine and mountain hemlock have all penetrated the new area to a width of 400 yds (366 m). Examples of downslope and upslope 'shift' are noted. Transitional gradients are common at the margins and in some cases extend right across the area.

14 BALLARD, T.M.; DOSSKEY, M.G. 1985. Needle water potential and soil-to-foliage flow resistance during soil drying: a comparison of Douglas-fir, western hemlock, and mountain hemlock. Can. J. For. Res. 15: 185-188.

Experiments were carried out in growth chambers on 1-yr-old seedlings in pots allowed to dry out over several days. Needle water potentials fell in the hemlocks (*Tsuga heterophylla* and *T. mertensiana*), but remained stable in Douglas-fir, as the soil dried. Resistance to water flow from soil to foliage was higher for the hemlocks and increased more steeply as the soil dried. The results account for the observation that water uptake was reduced relatively more for the hemlocks than for Douglas-fir as the soil water potential declined. When water uptake and resistance to it were expressed on a root-surface-area basis instead of a seedling basis, differences between the hemlocks and Douglas-fir were even more pronounced.

15 BARTON, G.M.; GARDNER, J.A.F. 1962. The occurrence of matairesinol in mountain hemlock (*Tsuga mertensiana*), western hemlock (*T. heterophylla*) and balsam (*Abies amabilis*). J. Org. Chem. 27: 322-3.

Matairesinol, a colorless, crystalline material (thought to be a lignan) observed in the ring shake of logs, was found to be a normal component of the heartwoods, but occurred only in negligible amounts in the sapwoods. Chemical and physical properties of matairesinol do not seem to differ among the species.

16 BELL, J.F.; MARSHALL, D.D.; JOHNSON, G.P. 1981. Tarif tables for mountain hemlock: developed from an equation of total stem cubic foot volume. Oreg. State Univ. For. Res. Lab., Res. Bull. 35, 46 p.

Tarif access tables were developed for mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) on the Deschutes National Forest in the Central Oregon Cascade Mountains from an equation for cubic-foot volume including top and stump (CVTS). These tables provide access to the comprehensive tree-volume tarif system.

17 BLONSKI, K.S.; SCHRAMEL, J.L. 1981. Photo series for quantifying natural forest residues: southern Cascades, northern Sierra Nevada. U.S. For. Serv., Gen. Tech. Rep. PSW-56, 145 p.

Photos and data sheets are given for various fuel-size classes for seven vegetation types: mixed conifer - ponderosa pine dominant, mixed conifer - white fir dominant, ponderosa pine, lodgepole pine, white fir, red fir, and mountain hemlock.

18 BOONE, R.D.; SOLLINS, P.; CROMACK, K. JR. 1988. Stand and soil changes along a mountain hemlock death and regrowth sequence. Ecology 69(3): 714-722.

Stand characteristics, dead wood, and soil carbon (C) and nitrogen (N) pools were measured through a wave-regenerated sequence of mountain hemlock death and regrowth created by *Phellinus weirii*. Stem density increased along the 96-yr old regrowth sequence, but was low in the 225-year-old mature stand. Total ecosystem carbon (TEC) dropped upon stand death and did not recover. Net ecosystem production (NEP) was negative just after stand death and zero thereafter. Mountain hemlock forests were found to be unusual in that little regeneration occurred in the older growth preceding, and in a 10-m band behind, the wave front. Particularly, high summer temperatures in the bare zone and the extremely N-poor soil are thought to be the causes of this delay in seedling regeneration. Tree biomass, dead wood, forest floor, mineral soil, and net ecosystem production characteristics of *Tsuga mertensiana* forests are detailed and compared to other conifer stands.

19 BROCKWAY, D.G.; TOPIK, C.; HEMSTROM, M.A.; EMMINGHAM, W.H. 1983. Plant association and management guide for the Pacific silver fir zone. Gifford Pinchot National Forest. U.S. For. Serv., Pac. Northwest Reg. R6-Ecol-130a-1983, 122 p.

Provides detailed descriptions of 14 plant associations, three of them containing mountain hemlock, *Tsuga mertensiana/Menziesia ferruginea, T. mertensiana/Rhododendron albiflorum* and *T. mertensiana/Vaccinium membrenaceum*. Vegetation cover, associated species, elevation range, slope position, landform and soil depths are provided by association. Mountain hemlock associations occur above 4000 ft (1220 m) where heavy snowpacks begin. Timber productivity is considered "low" for all three associations, and the opportunity for intensive management is listed as "poor."

20 BROOKE, R.C. 1966. Vegetation-environment relationships of subalpine mountain hemlock zone ecosystems. Diss. Abstr. 27: 2251B-2252B.

Quantitative and qualitative vegetation and environmental data from 114 sample plots were used to characterize and evaluate ecological relationships and dynamics previously little known for the Subalpine Mountain Hemlock Zone on the southwestern British Columbia mainland. Environmental analyses include the description of 36 kinds of soil representing several major categories. A combined vegetation-environment synthesis resulted in the characterization of ecosystematic units at zone, subzone, order, alliance, association, subassociation and variant levels. The Parkland Subzone is characterized by variation in snow depth and duration that results in sharp floristic and microclimatic patterns, and vegetation may influence microenvironmental dynamics by hastening snow melt and extending length of the growing season over short distances. The Forest Subzone is characterized by forested, moist to very moist units, and non-forested semi-terrestrial moor habitats. The subalpine mountain hemlock zone coincides with the main distributional area of *Tsuga mertensiana*.

21 BROOKE, R.C.; PETERSON, E.B.; KRAJINA, V.J. 1970. The subalpine mountain hemlock zone. Pages 147-349 *in* V.J. Krajina (editor). Ecology of Western North America, Dep. of Bot., Univ. B.C., Vancouver, B.C., Vol. 2, No. 2. 349 p.

Describes the mountain hemlock zone: climates and microclimates, soils, ecosystems and vegetation-environment relationships. The zone is divided into the Parkland Subzone and the Forest Subzone. Each is divided into three units: Parkland units are defined by average snow duration, while forest units are defined by seepage relationships. Tree growth and forest productivity are summarized. The influences on the zone of glacial history, volcanic ash and fires are discussed. Appendices contain plant lists, definitions of landscape, site, vegetation and soil descriptors, then present summarized results for 13 plant associations.

22 BROWN, R.W.; JOHNSTON, R.S.; JOHNSON, D.A. 1978. Rehabilitation of alpine tundra disturbances. J. Soil Water Conserv. 33: 154-160.

About 12% of alpine tundra in the U.S.A. has been disturbed by grazing, recreation, mining, mineral exploitation sites, construction sites, roads, off-road vehicles, pipe and power lines, reservoirs, and fire or landslides. Techniques for revegetation are reviewed, and a list of suitable plants, nearly all of which are native species (including mountain hemlock), is given.

23 CAMPBELL, S.J.; HAMM, P.B. 1989. Susceptibility of Pacific Northwest conifers to *Phytophthora* root rot. U.S. For. Serv. Tree Plant. Notes 40(1): 15-18.

Seedlings of *Tsuga mertensiana* and ten other conifer species were inoculated with five species of *Phytophthora* to determine susceptibility to *Phytophthora* root rot. The percentage of seedlings killed for each *Phytophthora* species, as well as the percentage of seedlings from which the inoculated species was recovered (percent re-isolation), and the average root-rot rating for each host-fungus combination were calculated. Mountain hemlock was found to be very susceptible to root rot, having the highest mortality of the conifers tested with 27.5% of the seedlings killed by the disease, and a root-rot rating of 1.74 (over 25% of the root system was killed). Although *Phytophthora*-caused seedling mortality is often confined to nurseries, stock quality and survival of seedlings after planting may also be adversely affected. Integrated control programs dealing with known susceptibilities to the root rot, rather than fungicides, are recommended for management.

24 CAMPO-DUPLAN, M. VAN. 1955. Quelques pollens d'hybrides d'Abietacées. [Pollen of hybrids in the Abietineae]. Silvae Genet. 4: 123-126. (In French).

Investigations on *Tsuga longibracteata, T. crassifolia* and *T. hookeriana* (= *T. mertensiana*) revealed features from which their hybrid character is concluded. These pollen grains have large air sacs and, therefore, one parent must be assumed which normally possesses pollen grains with air sacs. The hybrid *Abies vilmorini* is discussed also.

25 CARRIÈRE, È.A. 1867. Traité générale des conifères. Première partie. [General treatise on conifers. Part I.] Paris (privately printed): 245-255. (In French).

An early taxonomic evaluation of the genus *Tsuga*, describing the species *T. sieboldtii, sieboldtii nana, brunoniana, canadensis, canadensis nana, canadensis gracilis, mertensiana, hookeriana,* and *lindleyana*. Earlier names (synonyms) and references are provided.

26 CÁZARES, E.; TRAPPE, J.M. 1993. Vesicular endophytes in roots of the Pinaceae. Mycorrhiza 2: 153-156.

Vesicles and hyphae typical of vesicular-arbuscular mycorrhizas (VAM) were common in seedlings of *Pseudotsuga menziesii, Abies lasiocarpa* and *Tsuga mertensiana* growing in openings where herbaceous hosts of these fungi were common. Seedlings of *A. lasiocarpa, Tsuga heterophylla* and *T. mertensiana* growing under closed forest canopies also had vesicles, but with much lower incidence than seedlings in the openings. It is concluded that the ecological significance of abundant VAM-type endophytes in otherwise ectomycorrhizal hosts deserves comprehensive study.

27 CHOPINET, R. 1962. Les *Tsugas* et leurs hybrides. Revue Horticole 134: 208-211; II. Description des espèces: 229-235. III. Espèces d'origine hybride: 266-268. [The *Tsugas* and their hybrids. Rev. Hort. 134: 208-211; II. Species description: 229-235. III. Hybrids.] (In French).

These three articles review nomenclature of the genus and present a key (article I), descriptions, synonyms, drawings of foliage and cones (articles II and III) of 14 *Eutsuga* species and four "hybrid" species, the latter in the section *Hesperopeuce*. Mountain hemlock is called *Tsugo-Picea hookeriana* after the articles by Van Campo-Duplan and Gaussen.

28 CLAUSEN, J. 1965. Population studies of alpine and subalpine races of conifers and willows in the California high Sierra Nevada. Evolution 19: 56-58.

Pinus albicaulis, P. murrayana, Tsuga mertensiana, Salix monica and *S. orestera* evolved both subalpine erect and alpine horizontal (elfinwood) races at 10 000-11 000 ft (3050-3355 m) alt in Slate Creek Valley, east of the Sierra Nevada. The races interbreed in the border zone. Interspecific crossing appears to augment interracial crossing in the willows. The five species differ in tree-line altitude, frequency in relation to slope exposure, and other ecological factors. In this area, only alpine elfinwood forms of *Juniperus communis, Sorbus sitchensis, Salix petrophila, S. nivalis* and *S. reticulata* exist. *S. eastwoodiae* does not appear to develop an elfinwood form in the area but continues its erect form to 10 600 ft. The factors controlling ability to develop elfinwood forms are discussed.

29 COLEMAN, M.D.; HINCKLEY, T.M.; MCNAUGHTON, G.; SMIT, B.A. 1992. Root cold hardiness and native distribution of subalpine conifers. Can. J. For. Res. 22(7): 932-938.

Root and needle cold hardiness were compared in seedlings of subalpine conifers to determine if differences existed among species originating from either cold continental climates or mild maritime climates. *Abies amabilis* and *Tsuga mertensiana* are exclusively distributed in maritime environments, while *Abies lasiocarpa* and *Pinus contorta* are more generally distributed in both continental and maritime environments. Because of the differing winter soil conditions of these two climatic types, special emphasis was placed on root cold hardiness. Cold hardiness for root samples, as measured by a decrease in the electrolyte leakage, was much greater for *A. amabilis* and *A. lasiocarpa* than for *P. contorta* and *T. mertensiana* (-11.4, -11.5, -7.5 and -7.5°C, respectively). Thus, subalpine conifer species distribution was not limited by root cold hardiness. Root cold hardiness of field-grown seedlings paralleled changes in soil temperature through February. Under constant temperature conditions (3°C) the maximum cold hardiness achieved in six weeks was not subsequently maintained in *A. amabilis* and *A. lasiocarpa*. Injury in unhardened roots was coincident with bulk freezing, whereas hardened roots were able to tolerate bulk freezing. All species except *P. contorta* reached needle cold hardiness levels below -40°C.

30 CONNER, R.C.; O'BRIEN, R.A. 1993. Montana's forest resources. U.S. For. Serv., Res. Bull. INT-81, 96 p.

Describes forest types and ownership; stand composition, stocking, volume, productivity; removal, mortality and inventory; harvesting and habitat types. Tables present data on all aspects. Forest land totals 22 509 648 ac (8 862 066 ha). Growing stock in 1989 totalled 28 658 800 000 cu ft (811 634 000 cu m). Net annual growth in 1988 was 657 989 000 cu ft (18 635 000 cu m). Annual timber removal in 1988 was 249 728 000 cu ft (7 072 444 cu m). Mountain hemlock is considered a "miscellaneous western softwood" in land-inventory classes and in growing-stock summary. This entry ranks low in all categories.

31 CROMACK, K., JR.; ENTRY, J.A.; SAVAGE, T. 1991. The effect of disturbance by *Phellinus weirii* on decomposition and nutrient mineralization in a *Tsuga mertensiana* forest. Biol. Fert. Soils 11: 245-249.

Microbial biomass in the top 7 cm of soil was higher in a mountain hemlock (*T. mertensiana*) old-growth forest soil than in the regrowth forest soil after *P. weirii* had caused disturbance. However, *T. mertensiana* needle decomposition rates were higher in the regrowth than in the old-growth forest. The results suggest that higher needle decomposition rates increased the mineralization of N, P and K, which may lead to increased soil fertility and faster tree growth rates in the regrowth forest.

32 CWYNAR, L.C. 1990. A late quaternary vegetation history from Lily lake, Chilkat peninsula, Southeast Alaska. Can. J. Bot. 68(5): 1106-1112.

Pollen and macrofossil analyses of radiocarbon-dated cores from Lily lake allowed for a proposed reconstruction of the history of Pacific coastal forests. It was proposed that several species dominated the forest in succession. *Tsuga mertensiana* was found to be one of the latest components of these forests.

33 DAHLGREN, R.A.; VOGT, K.A.; UGOLINI, F.C. 1991. The influence of soil chemistry on fine root aluminum concentrations and root dynamics in a subalpine Spodosol, Washington State, USA. Plant Soil 133: 117-129.

The relation between root Al concentrations and Al fractions in soil solution was examined in a mature *Abies amabilis* ecosystem in the Cascade Range. Naturally acidic soils in these ecosystems lead to high concentrations of aqueous Al in soil solutions and contribute to biocycling of Al by the *A. amabilis/Tsuga mertensiana* stand. Root concentrations of Al were very closely related to aqueous Al activities, but poorly correlated with total aqueous Al. Solution Al:Ca molar ratios followed a seasonal cycle: low during autumn and high during spring. Ratios remained <1 throughout the year in the Oa horizon while they varied between 2 and 14 in E and Bhs horizons. Vertical distribution of roots and mortality of fine roots may be linked to soil solution Al:Ca ratio. Root cation exchange capacity ranged between 180 and 225 *f* mol/g and the exchangeable Al fraction represented 12-17% of total Al content in the root. Evidence for solid-phase co-precipitates of Al with PO_4 and oxalate was indicated from selective dissolution of root tissue. Sufficient quantities of PO_4 and oxalate exist in roots to tie up 20-40% of Al present in the roots of Oa and E horizons, but only 9% of that present in Bhs horizon. Species differences in distribution of Al between above-ground and below-ground components may be dictated by these retention processes in fine roots.

34 DAHMS, W.G.; FRANKLIN, J.F. 1965. Mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). Pages 712-716 *in* H.A. Fowells (comp.). Silvics of forest trees of the United States. U.S. Dep. Agric., Agric. Handb. 270. Washington, D.C. 762 p.

Reviews habitat conditions (climate, soils and topography, associated trees), life history (reproduction and early growth, sapling stage to maturity), and races and hybrids of mountain hemlock. Spread over 25° of latitude and 38° of longitude, the species flourishes under heavy precipitation in the south, to less humid areas subject to greater temperature extremes in the north; soils loose, coarse-textured, and well-drained; occurs in a wide variety of mixtures with other species. Some hybridization with western hemlock has been noted.

35 DAUBENMIRE, R.; DAUBENMIRE, J.B. 1968. Forest vegetation of eastern Washington and northern Idaho. Wash. Agric. Exp. Stn., Tech. Bull. 60. Wash. State Univ., Pullman. 104 p.

Four habitat type series are identified and described: ponderosa pine, Douglas-fir, western hemlock and *Abies lasiocarpa*. The last is subdivided into three habitat types: *A. lasiocarpa* (AL) - *Pachistima myrsinites*; AL - *Xerophyllum*; *Tsuga mertensiana* - *Xerophyllum*. Mountain hemlock is absent from the AL - *Xerophyllum* type, but reproduces in its habitat type. This type was found "only in northern Idaho," but "undoubtedly" would occur in western Montana also. Mountain hemlock occurs also as a major climax component of the *Tsuga mertensiana* - *Menziesia* habitat type and as a minor climax component of the AL - *Menziesia* type. Compared to its associated tree species (Engelmann spruce, *A. lasiocarpa* and *Pinus albicaulis*), mountain hemlock is "an exception" in not occupying open habitats below its range.

36 DICKMAN, A.; COOK, S. 1989. Fire and fungus in a mountain hemlock forest. Can. J. Bot. 67(7): 2005-2016.

A study of ecological structure patterns of various stands of *Tsuga mertensiana* at elevations of 1500 to 2200 meters totaling 18 000 ha found them to be influenced by forest fires and the fungus *Phellinus weirii*. Factors discussed were: the dynamics and extent of fire, *P. weirii* disturbances in mountain hemlock forests, the natural succession after fire and fungus-caused mortalities, and the role of *Phellinus weirii* in the ecosystem. Fungal isolates from infestations were collected and clonal analyses of individual *Phellinus weirii* genotypes were completed to determine the age of the fungus, the pattern of infestations, and the survival of the fungus in fires. *P. weirii* was found to be controlled by fire outbreaks, but the fungus weakens the stands and may enhance the probability of stand-destroying fires. The frequency of fire outbreaks influenced species dominance and degree of fungal infection.

37 DOUGLAS, G.W. 1971. The alpine-subalpine flora of the North Cascade Range, Washington. Wasmann J. Biol. 29: 129-168.

Stands differed markedly in structure and composition, with variations in understorey depending on openness of the canopy. Floristically, the mountain hemlock-Pacific silver fir association is among the poorest in the Pacific Northwest, averaging only eight species per stand.

38 DOUGLAS, G.W. 1972. Subalpine plant communities of the western North Cascades, Washington. Arc. Alp. Res. 4: 147-166.

The mountain hemlock-Pacific silver fir type was recognized as the single climax association in the subalpine parkland subzone of the mountain hemlock zone. The two phases of the association are the "closed," in which mountain hemlock is dominant with Pacific silver fir as an associate and subalpine fir as an occasional associate, and the "open," in which mountain hemlock dominance decreases as Pacific silver fir increases.

39 DOUGLAS, G.W.; BALLARD, T.M. 1971. Effects of fire on alpine plant communities in the North Cascades, Washington. Ecology 52: 1058-64.

Alpine heath and krummholz communities were studied on Sourdough Ridge (1900 m alt) 29 yr after burning. Fire caused changes in the structure and composition (species presence, frequency and coverage) of both communities, and in the acidity and humus type of the soils. Unburned krummholz stands were dominated by *Abies lasiocarpa* and *Tsuga mertensiana* with *Phyllodoce empetriformis* and *Vaccinium deliciosum* as the major understorey species. Fire caused substantial and persistent increases in the diversity of both communities.

40 DUNWIDDIE, P.W. 1987. Macrofossil and pollen representation of coniferous trees in modern sediments from Washington. Ecology 68: 1-11.

Pollen and conifer-needle macrofossils were collected from surface sediments in 30 ponds near Mount Rainier to study representation of forest trees in data from modern sediments. Percentages of major taxa calculated from these data were compared with basal area measures of forest composition within 30 m of each pond. Macrofossil percentages of *Abies amabilis*, *A. lasiocarpa*, *Pseudotsuga menziesii*, *Tsuga heterophylla*, and *T. mertensiana* were significantly correlated with their basal areas in nearby forests; none was greatly over-represented or under-represented. Macrofossil assemblages were similar in replicate samples from surface sediments, as well as from parallel cores spanning 6000 yr. Fossil needle assemblages can therefore provide estimates of past species composition in coniferous forests in the Pacific Northwest. Widespread distribution of pollen was also demonstrated by high pollen percentages of taxa that were absent from the flora at the sample sites, such as *Alnus rubra*. Pollen of *Pinus* and *T. heterophylla* was over-represented, whereas that of *Abies* and *T. mertensiana* was under-represented. Pollen percentages of most conifer taxa were twice the values reported in another study from Mount Rainier using moss polsters. Comparisons between the macrofossil and the pollen data indicate that conifer macrofossil assemblages more accurately reflect forest composition near sample sites, and also provide greater taxonomic resolution.

41 DYRNESS, C.T.; FRANKLIN, J.F.; MOIR, W.H. 1974. A preliminary classification of forest communities in the central portion of the western Cascades in Oregon. Int. Biome Prog., Conif. For. Biome, Ecosys. Anal. Studies, Bull. No. 4. 123 p.

Two distinct forest zones, the *Tsuga heterophylla* (300 to 1050 m in elevation) and the *Abies amabilis* (1050 to 1550 m), were recognized. The location of these zones is largely a function of temperature (elevation), while distribution of individual communities within a zone is controlled mainly by moisture availability. Mountain hemlock occurs in four forest communities in the *Abies amabilis* zone: Abam-Tsme/Xete, Abam/Vame/Xete, Abpr/Actr and Abpr/Clun. Mountain hemlock is most prominent and constant in the first two communities and will regenerate successfully, perhaps forming pure stands on the poorest sites. Thus, it may be a major seral and climax species.

42 EBELL, L.F.; SCHMIDT, R.L. 1964. Meteorological factors affecting pollen dispersal on Vancouver Island. Pub. No. 1036. Can. Dep. For., Ottawa, ON. 29 p.

Records of pollen dispersal and meteorological data were collected over three seasons along an elevational transect. There appeared to be a relationship between July temperatures and the initiation of reproductive primordia in mountain hemlock, Douglas-fir, grand fir, amabilis fir and alpine fir. The primary difference between species in their reactions to meteorological factors lay in the time at which pollen release commenced.

43 EDMONDS, R.L.; THOMAS, T.B.; MAYBURY, K.P. 1993. Tree population dynamics, growth, and mortality in old-growth forests in the western Olympic Mountains, Washington. Can. J. For. Res. 23: 512-519.

In 1985 in the West Twin Creek watershed, the principal tree species being Douglas-fir, western hemlock, Pacific silver fir, western redcedar and Sitka spruce, stem densities for trees >5 cm dbh averaged 489 and 476/ha in the lower (180 m) and upper (850 m) reaches, respectively. For the Hoh Lake watershed, the principal tree species being Pacific silver fir, mountain hemlock and yellow cedar, stem diameters (>5 cm dbh) averaged 508/ha. At both sites, a decline of 3-5% in stem density occurred from 1980-1985. Causes of mortality are discussed. During the same 5-yr period, there was a 5% increase in basal area in the lower West Twin Creek area, 1% decrease in ba in the upper West Twin Creek area, and a 4% decrease at Hoh Lake. Although mountain hemlock had a relatively low mortality rate, its basal area declined.

44 EDWARDS, D.G.W.; MEAGHER, M.D.; EL-KASSABY, Y.A. 1993. Genetic diversity in mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). Pages 68-71 *in* V.G. Marshall (compiler). Proc. Forest Ecosystem Dynamics Workshop, Feb. 10-11, 1993. Canada-British Columbia Partnership Agreement on Forest Resource Development: FRDA II, FRDA Rep. 210.

Summarizes the first year of a 5-yr study to investigate genetic variation in mountain hemlock via the mating system, reproductive success and germination ecology, seedling attributes, intra- and inter-population genic variation, morphology of foliage, cones and seeds from collections *in situ*, genetic relationships to other conifers via controlled-hybridization attempts, and associated organisms (insects and pathogens) of interest. Preliminary indications are that mountain hemlock germination remains temperature sensitive even after seeds have been stratified for 3 months. For accelerated ageing (simulated storage) tests, 100% RH at 37.5°C gave the clearest results.

45 EIS, S.; CRAIGDALLIE, D.; POWELL, G.R. 1983. Reproduction of conifers: a handbook for cone crop assessment. Mountain hemlock. Can. For. Serv., Gen. Tech. Rep. 31: 31-32.

A brief overview illustrating reproduction in *Tsuga mertensiana* is given. Bud formation, bud morphology, the mechanisms of pollination and fertilization, seed production, and seed dispersal are described.

46 ELWES, J.H.; HENRY, A. 1907. The trees of Great Britain and Ireland. Edinburgh (privately printed), vol. II: 227-248.

Describes genera of Coniferae cultivated in the British Isles. The genus *Tsuga* is divided into two sections, *Hesperopeuce* (*Tsuga pattoniana* only), and *Micropeuce* which includes eight other species. Species are separated in a key. Earlier botanical names, with references, are provided. *T. mertensiana* is named *T. pattoniana* to avoid confusion with western hemlock (*T. albertiana*). Two varieties of mountain hemlock are described based on foliar colour: var. *typica* with bluish leaves, and var. *jeffreyi* with greenish leaves.

47 ENGELMANN, G. 1879. Abietinae. Pages 117-128 *in* S. Watson, Botany of California 2. Univ. Press., Cambridge, Mass.

Includes a detailed botanical description of the genus *Tsuga*, and the species *T. mertensiana* and *T. pattoniana*.

48 FALLER, A., III; JACKSON, M.T. 1967. Vegetation gradients on Wizard Island, a volcanic cinder cone in Crater Lake, Oregon. Abstr. in Proc. Indiana Acad. Sci. 77: 183.

Presents information on the forest belts, including a rather dense *Tsuga mertensiana/Abies magnifica* var. *shastensis/Pinus monticola* forest encircling the base of the cone, a less dense stand similar in composition on the western lava flow, and a scattered stand dominated by *Pinus albicaulis* encircling the crater.

49 FARJON, A. 1988. Taxonomic notes on Pinaceae. I. Proc. Koninklijke Nederlandse Akademie van Wetenschappen, Series C: Biol. and Med. Sci. 91: 31-42.

A critical review, based on herbarium specimens of four taxa (*Abies concolor* var. *lowiana*, *A. nepholepsis* f. *chlorocarpa*, *A. pardei* and *Pseudotsuga wilsoniana*), and description of a new subspecies (*Tsuga mertensiana* subsp. *grandicona*).

50 FARJON, A. 1990a. A bibliography of conifers: selected literature on taxonomy and related disciplines of the Coniferales, and especially of the families Cupressaceae (with Taxodiaceae) and Pinaceae. Regnum Veg. vol. 122. Königstein, Germany; Koeltz Scientific Books. 129p.

A listing of approximately 2100 references, many with annotations, on taxonomy and related disciplines focussed on two large families, the *Cupressaceae* and *Pinaceae*, and including the *Taxodiaceae* and a few taxa belonging to other families. Mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), plus sub-species *grandicona* Farjon and *mertensiana*, and *T. mertensiana* var. *jeffreyi* (Henry) Scheider, together with *Hesperopeuce mertensiana* (Bong.) Rydb., are listed.

51 FARJON, A. 1990b. Pinaceae: drawings and descriptions of the genera *Abies, Cedrus, Pseudolarix, Keteleeria, Nothotsuga, Tsuga, Cathaya, Pseudotsuga, Larix* and *Picea*. Regnum Veg. vol. 121. Königstein, Germany. Koeltz Scientific Books. 330 p.

Notes for the genera include description, classification, keys to sections/subsections/species, ecology, and distribution. Notes for the species include habit, ecology, and distribution, with information on subspecies and varieties. Line drawings illustrate the tree, shoot, cone, leaf, seed, etc. and distribution. A glossary of botanical and ecological terms, and an index of botanical names, are included.

52 FARJON, A.; PAGE, C.N.; SCHELLEVIS, N. 1993. A preliminary world list of threatened conifer taxa. Biod. and Conserv. 2: 304-326.

Conifers (the fast-growing 'softwoods' of the world) occur as the dominant plants of most temperate rainforest communities. Almost all are tall forest trees whose high commercial value creates conservation vulnerability for many local species in the increasingly resource-hungry world. Of an estimated 600 species in the world, 362 would fall into this category and consequently appear on this list. This paper provides a preliminary analytical world census list of 416 conifer taxa (species, subspecies and varieties) considered to be of conservation concern. The list includes mountain hemlock.

53 FELLER, M.C. 1982. The ecological effects of slashburning with particular reference to British Columbia: a literature review. B.C. Min. For., Victoria, B.C. Land Manag. Rep. 13, 60 p.

Mountain hemlock is a very shade-tolerant species, but it does not require shade for establishment. Slashburning in northern Idaho produced better stocking of natural regeneration compared to leaving slash untreated. However, scarification generally produced better stocking than did burning. Slashburning in Oregon increased the time taken by mountain hemlock to reach 60% stocking. There is insufficient information available about the effects of slashburning in British Columbia.

54 FILIP, G.M.; SCHMITT, C.L. 1979. Susceptibility of native conifers to laminated root rot east of the Cascade Range in Oregon and Washington. For. Sci. 25: 261-265.

The results of a study of 1527 coniferous trees (*Pseudotsuga menziesii, Larix occidentalis, Pinus contorta, Abies grandis, Abies magnifica* var. *shastensis*, and *Tsuga mertensiana*) in 0.09-ha plots in each of 10 centres of *Phellinus (Inonotus) weirii* infection. *T. mertensiana* had the highest infection and mortality, and *P. contorta* was the least affected. The most common indicator of infection was mortality in susceptible species, and internal decay in resistant species. Healthy trees were exposed to large amounts of fungal inoculum, as indicated by inoculum index (Ii).

55 FONDA, R.W. 1967. Ecology of montane and subalpine forests, Olympic Mountains, Washington. Diss. Abstr. 28, 4890B.

The climate of the Olympic Mts. ranges from wet maritime conditions on the windward slopes to a rainshadow on the lee slopes. Five community types were recognized in the montane zone: *Abies amabilis-Tsuga heterophylla/Oxalis* forests occupy all the western slopes from 550 to 1100 m, under a maritime climate. *Abies amabilis-Tsuga heterophylla* forests are confined to river terraces from 760 to 1125 m in the eastern Olympics. *Tsuga heterophylla-Pseudotsuga menziesii* forests are most commonly found on northern exposures in the eastern Olympics, and in central valleys with abundant precipitation. *Pseudotsuga menziesii-Tsuga heterophylla* forests are found from 550 to 1125 m on south-facing slopes in the eastern montane zone. *Pseudotsuga menziesii* forests occupy very dry, exposed sites on south and west-facing slopes in the eastern mountains between sea level and 1400 m. In the subalpine zone, *Abies amabilis-Tsuga mertensiana* forests occur between 1100 to 1650 m, and *Abies* *lasiocarpa* forests between 1300 to 1800 m on exposed ridges. Aspect and snowpack are strong determinants in the sub-alpine zone.

56 FONDA, R.W.; BLISS, L.C. 1969. Forest vegetation on the montane and subalpine zones, Olympic Mountains, Washington. Ecol. Monogr. 39: 271-301.

Describes the location, composition and structure of the five montane forest types composed of *Abies amabilis, Tsuga heterophylla, Pseudotsuga menziesii* etc., and the two subalpine forest types characterized by *A. amabilis, Tsuga mertensiana* and *A. lasiocarpa*, in relation to climate and soils, the effects of fire, etc.

57 FRANKLIN, J.F. 1962. Mountain hemlock: a bibliography with abstracts. U.S. For. Serv., Pac. Northwest For. Range Exp. Stn., Res. Pap. 51, 50 p.

Lists 290 references to *Tsuga mertensiana*, and approximately 100 of the more significant are supported by abstracts. A detailed subject index is provided.

58 FRANKLIN, J.F. 1965. Tentative ecological provinces within the true fir-hemlock forest areas of the Pacific Northwest. U.S. For. Serv., Res. Pap. PNW-22, 31 p.

These forests, which occupy approximately 3 million ac (1.215 million ha) at medium and high altitudes in the mountains of Oregon and Washington, are classified into 11 ecological provinces based on differences in geology, physiography, climate, soils, and the relative importance of constituent trees. The characteristic species are *Abies amabilis, A. procera, A. magnifica* var. *shastensis, A. lasiocarpa, Tsuga heterophylla, T. mertensiana*, and *Pinus monticola*. Typical features of the topography and forest type are illustrated, and the main characteristics of each province are described.

59 FRANKLIN, J.F. 1966. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Diss. Abstr. 27: 1746B-7B.

Forest communities and soils were examined at more than 200 sites in the cool-moist *Abies amabilis* and *Tsuga mertensiana* zones, at 2000-6000 ft (610-1830 mm). Fifteen distinctive plant associations are described, with a key for their identification. *Abies amabilis* is the major climax tree species in both zones. Soils within the study area are predominantly podzolic.

60 FRANKLIN, J.F. 1968. Cone production by upper slope conifers. U.S. For. Serv., Res. Pap. PNW-60, 21 p.

Gives tables showing cone crops of *Abies* spp., *Tsuga mertensiana, Pinus monticola* and *Picea engelmannii* on 47 plots in Oregon and Washington in 1961-67, and discusses the variation in production between trees within plots, the frequency of cone crops and the selection of prolific seed producers to be left in partial fellings.

61 FRANKLIN, J.F. 1980. Mountain hemlock, type 205. Pages 85-86 *in* F.H. Eyre (ed.). Forest cover types of the United States and Canada. Soc. Am. For., Washington, D.C. 148 p.

Describes the subalpine forest type dominated by mountain hemlock: major and minor associated species, geographic distribution, ecological relationships and ecological variants.

62 FRANKLIN, J.F.; CARKIN, R.; BOOTH, J. 1974. Seeding habits of upper slope tree species. I. A 12 year record of cone production. U.S. For. Serv., Res. Note. PNW-213, 12 p.

Annual cone production by several important upper-slope species important in the true fir-hemlock forests of the Pacific Northwest, including *Tsuga mertensiana*, was observed in 52 plots over a 12-yr period. Annual cone counts on dominant and co-dominant trees of the subject species were repeated and annual cone production is presented. Factors discussed include: cone production by species, the most recent five years' production compared to earlier data, cone production in mixed stands, and the record crops of individual trees. There is a surprising consistency in cone production in almost all species and locations since 1968.

63 FRANKLIN, J.F.; DYRNESS, C.T. 1973. Natural vegetation of Oregon and Washington. U.S. For. Serv., Gen. Tech. Rep. PNW-8, 417 p.

This book is based on earlier work, but contains much new information and a number of appendices including an index to plant communities and brief definitions of the principal soil types. Descriptions of each vegetation zone include composition and succession, as well as variations associated with environmental gradients.

64 FRANKLIN, J.F.; EMMINGHAM, W.; JASZKOWSKI, R. 1983. True fir - hemlock. Pages 13-15 *in* R.M. Burns (tech. compiler). Silvicultural systems for the major forest types of the United States. U.S. Dep. Agric., Agric. Handb. 445. Washington, D.C. 191 p.

True fir-hemlock forests varied in habitat types, with *Tsuga mertensiana* forests found at higher elevations in the Cascade and Coast Ranges of Oregon and Washington, and the Olympic Mountains. The variety of conditions in different locations influences the genetic variation of mountain hemlock. *Tsuga mertensiana* was found to be more adversely affected than other conifers (*Abies amabilis, Tsuga heterophylla, Chamaecyparis nootkatensis, A. procera, Pseudotsuga menziesii*) by pests and diseases, which may limit its management potential. Possibilities of further studies on "resistant" individual trees are mentioned. Regeneration, growth rates, fire risk and its impact, as well as management systems and their impact are discussed also.

65 FRANKLIN, J.F.; KRUEGER, K.W. 1968. Germination of true fir and mountain hemlock seed on snow. J. For. 66(5): 416-417.

Observations on the premature germination of mountain hemlock and true fir species seeds in late-persisting snowbanks in the Cascade and Coast Ranges of the Pacific Northwest were documented. The frequency of germination in snow is given for several species, with *Tsuga mertensiana* germinants found in only three out of the 25 separate occasions that true fir and mountain hemlock germinants were found in snowbanks. Radicles for true firs were 1/2 (12.5 mm) to 3 in (7.5 mm) long and 1/8 (3 mm) to 1/2 in (12.5 mm) long for mountain hemlock. Few of the seedlings germinating on the snow would become established and broadcast seeding on snowbanks is speculated to fail due to premature germination in late-persisting snowpacks.

66 FRANKLIN, J.F.; MITCHELL, R.G. 1967. Successional status of subalpine fir in the Cascade Range. U.S. For. Serv., Res. Pap. PNW-46, 16 p.

Describes succession of *Abies lasiocarpa* on 12 sites in Washington and Oregon and relationships with up to 14 coniferous species. Both closed-forest and timberline stands were assessed. Mountain hemlock was a "major" associate in both closed-forest and timberline stands. Mountain hemlock succeeds subalpine fir because of its greater shade tolerance, although it can be a pioneer also in some situations, perhaps starting invasions of subalpine meadows. Effects of insect attacks on associations are discussed.

67 FRANKLIN, J.F.; MOIR, W.H.; DOUGLAS, G.W.; WIBERG, C. 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. Arc. Alp. Res. 3: 215-24.

Investigations in the forest/tundra ecotone revealed massive invasion of sub-alpine meadows by several tree species, especially *Abies lasiocarpa* and *Tsuga mertensiana*. Invasion was generally most intense in 1928-1937, and little invasion has occurred since ca 1945; climatic change is the factor most likely to influence invasion. Invasion density was low in meadow types dominated by tall forbs and grass, and high in types dominated by low forbs and shrubs, but growth rates of established trees were greatest in the tall forb and grass communities.

68 FRANKLIN, J.F.; MOIR, W.H.; HEMSTROM, M.A.; GREENE, S.E.; SMITH, B.G. 1988. The forest communities of Mount Ranier National Park. Sci. Monogr. Ser. U.S. Nat. Park Serv. 19: 194 p.

A forest classification scheme for several forest types (found in Mount Rainier National Park) to 1800 m elevations, including *Tsuga mertensiana*, is discussed. The plant communities, the effects of natural disturbances and other environmental variables such as snowpack and moisture, were studied.

69 FRANKLIN, J.F.; SMITH, C.E. 1974. Seeding habits of upper-slope tree species. II. Dispersal of a mountain hemlock seedcrop on a clearcut. U.S. For. Serv., Res. Note. PNW-214, 9 p.

Tsuga mertensiana seedfall on a clearcut in the southern Oregon Cascade Range was studied to analyze natural-regeneration difficulties with this species. Seed production and dissemination were measured using four seed-trap transects. *Tsuga mertensiana* seed dispersal patterns were found to decline rapidly as the distance from the stand edge increased. Marginal stand conditions, such as the number and size of seed bearing trees, also appear to strongly influence the seedfall levels on adjacent clearcuts. In years of good seed crops, the quantity of seed landing in the clearcut was adequate (50 000 to 100 000 sound seeds per acre) (20 000 to 40 000 per ha), so other factors such as frost and drought appear to be the factors limiting natural regeneration of mountain hemlock on clearcuts.

70 FRANKLIN, J.F.; SWANSON, F.J.; HARMON, M.E.; PERRY, D.A.; SPIES, T.A.; DALE, V.H.; MCKEE, A.; FERRELL, W.K.; MEANS, J.E.; GREGORY, S.V.; LATTIN, J.D.; SCHOWALTER, T.D.; LARSEN, D. 1992. Effects of global climatic change on forests in northwestern North America. Pages 244-257 *in* R.L. Peters and T.E. Lovejoy (eds.). Global warming and biological diversity. Yale Univ. Press, New Haven, Conn., U.S.A. 386 p.

Explores the potential effects of predicted changes in global climate on the coniferous forests of the Pacific Northwest. Climatic warming will cause existing mountain hemlock forests to increase in productivity. The boundaries of the mountain hemlock zone, within which new mountain hemlock forests become established after disturbance, will increase in elevation, and the zone will decrease in area. Sites occupied currently by communities typical of the mountain hemlock zone could be replaced by communities characteristic of the western hemlock zone if mean annual temperature increases by 4°C.

71 GHOLZ, H.L. 1982. Environmental limits on above-ground net primary production, leaf area, and biomass in vegetation zones of the Pacific Northwest. Ecology 63: 469-481.

Mature vegetation from 8 of 12 major vegetation zones in Oregon and Washington was sampled in 1976-7 along a transect from the Pacific Coast to the east slopes of the Cascade Mts. Above-ground, overstorey net primary production (NPP, the sum of annual stem, branch and foliage production) ranged from 0.3 to 15 t/ha, above-ground biomass from 3 to 1500 t/ha, and the area of all sides of leaves from 1 to 47 ha/ha. Minimal values were found in the shrub-steppe zone, and maximal values in the coastal forest zone. Maximal leaf area index, biomass and NPP were strongly related to an index of growing-season water balance and to mean minimum air temperature in January. Of the water balance components, evaporative demand alone accounted for more than 90% of the variation in leaf area index. Biomass and NPP increased linearly up to a leaf area of approx. 30 ha/ha; above this, biomass continued to increase while NPP decreased. Except in the coastal forest zones, NPP was less than the maximum values reported for other mature systems with the same range of leaf area index. Compared with other temperate forest regions with the same NPP, the Pacific Northwest has more annual precipitation and averages twice the ba and biomass.

72 GHOLZ, H.L.; GRIER, C.C.; CAMPBELL, A.G.; BROWN, A.T. 1979. Equations and their use for estimating biomass and leaf area of plants in the Pacific Northwest. Oreg. State Univ. For. Res. Lab., Rep. Pap. 41, 37 p.

Sets of equations are presented for 43 major species of trees, including mountain hemlock, shrubs and herbs in the Pacific Northwest. The fully documented equations relate foliar biomass and area, stem biomass, branch biomass, and other component sizes to diameter at breast height, basal diameter, and other dimensions easily measured in the field. The report includes instructions and cautions about use of the equations.

73 GJOVIK, L.R.; ROTH, H.G.; DAVIDSON, H.L. 1972. Treatment of Alaskan species by double-diffusion and modified double-diffusion methods. U.S. For. Serv., For. Prod. Lab., Res. Pap. FPL 182, 19 p.

Poles of *Picea glauca* var. *albertiana, P. sitchensis, Tsuga mertensiana* and *Populus balsamifera* were subjected to several variations on a standard preservative treatment consisting of soaking successively in solutions of $CuSO_4$ and Na_2HAs0_4. Penetration and retention were increased by partial seasoning (to 30-40% mc) before treatment, by incising, and by controlling temperature during the first ($CuSO_4$) stage of the treatment.

74 GOHEEN, D.J.; FILIP, G.M. 1980. Root pathogen complexes in Pacific Northwest forests. Plant Dis. 64: 793-794.

Surveys were made in 1976-8 of 73 areas in Oregon and Washington with trees dead or dying from root disease. Root systems of the trees (6 species) were excavated and isolations made in 22 of the 73 areas; root crowns of dead or dying trees and their apparently healthy neighbours were examined. In 12 areas, complexes of two or more pathogens (*Armillaria mellea* with *Phellinus* (*Inonotus*) *weirii* or *Fomes annosus* (*Heterobasidion annosum*) or *Ceratocystis wageneri*, or *P. weirii* with *C. wageneri* plus or minus *A. mellea*) occurred in discrete infection centres, colonizing roots of adjacent or the same trees. In the remaining 61 areas the most common (single) pathogens were *I. weirii* (49%), *A. mellea* (26%) and *C. wagneri* (23%). One Oregon stand (Warm Springs) contained mountain hemlock, Douglas-fir and noble fir of age 80; of 42 trees, 100% were infected, most (65%) by *C. wageneri*. No breakdown by species is given.

75 GOHEEN, D.J.; HANSEN, E.M. 1978. Black stain root disease (*Verticicladiella wagenerii*) in Oregon and Washington *Pseudotsuga menziesii*, *Pinus ponderosa* and *Tsuga mertensiana*. Plant Dis. Rep. 62(12): 1098-1102.

In western Oregon and Washington, Douglas-fir is the major host of black root disease, but ponderosa pine and *Tsuga mertensiana* also have been found infected. The disease usually causes rapid tree decline and death. It frequently predisposes trees to attack by bark beetles and woodborers, and infection by *Armillaria* root disease. Long-range spread of the black stain root disease is believed to be a result of insect vectors such as root-feeding scolytids and curculionids. As *Verticicladiella wagenerii* is believed to be host specific, and thus unable to survive after the tree's death, control measures such as removing infection centres and creating buffer zones are suggested.

76 GRAUMLICH, L.J.; BRUBAKER, L.B. 1986. Reconstruction of annual temperature (1590-1979) for Longmire, Washington, derived from tree rings. Quat. Res. 25: 223-234.

Annual growth records from trees at timberline in the Cascade Range were correlated with variations in temperature and snow depth and were used to reconstruct climatic variation in the past. Results indicate that growth of mountain hemlock (and sub-alpine larch) is positively correlated with July to September temperature and negatively correlated with March snow depth when the latter is at or below average. During years of above-average snow depth, temperature had little effect on mountain hemlock (but had a negative effect on growth of sub-alpine larch). Reconstruction of mean annual temperatures showed that the period 1590-1900 was approximately 1°C cooler than the twentieth century.

77 GRAUMLICH, L.T.; BRUBAKER, L.B.; GRIER, C.C. 1989. Long term trends in forest net primary productivity: Cascade mountains, Washington. Ecology 70(2): 405-410.

Estimates of annual net primary productivity since 1880 for four high-elevation forest stands in the *Tsuga mertensiana*, *Tsuga heterophylla*, and *Abies amabilis* zones, in western Washington, indicated that productivity has increased 60% during the 20th century. Because these stands were separated by up to 200 km and differed in species composition, elevation, and time since establishment, the observed trends in productivity imply a response to region-wide changes in environmental conditions rather than to site-specific stand dynamics. Annual production is significantly correlated with long-term variation in summer temperature and short-term variation in annual precipitation since 1893, the beginning of continuous local meteorological records. Production is not related to the concentration of atmospheric carbon dioxide, suggesting that direct carbon dioxide fertilization is currently unimportant in these forests.

78 GRIER, C.C. 1988. Foliage loss due to snow, wind, and winter drying damage: its effects on leaf biomass of some western conifer forests. Can. J. For. Res. 18: 1097-1102.

Damage to forest canopies by wind, snow, or winter desiccation significantly reduced stand leaf biomass and area below "steady-state" levels in twelve western coniferous forests, including mountain hemlock. Leaf biomass sampled for an average of 4 yr was reduced by as much as 36.3, 34.5, and 42.2% by single wind damage, snow breakage, or winter desiccation events, respectively. Foliage loss exceeded annual foliage production as estimated from leaf litterfall in about half the stands where damage occurred. Production efficiency (Mg dry matter·ha^{-1}·yr^{-1}·Mg^{-1} foliage) by remaining foliage appeared to increase after damage. The mountain hemlock forests suffered low canopy damage, whether measured by green litterfall, senescent-leaf litterfall or reduction in canopy mass.

79 GRIER, C.C.; VOGT, K.A.; LEE, K.M.; TESKEY, R.O. 1985. Factors affecting root production in subalpine forests of the northwestern United States. Pages 143-149 *in* H. Turner and W. Tranquillini (editors). Establishment and tending of subalpine forest: research and management. Proc. 3rd Intern. Workshop, IUFRO Project Group P1.07-00, Riederalp, Switzerland, 1984. Berichte, Eidgenössische Anstalt für das Forst. Versuchsw., Switzerland, 1985, No. 270.

Studies of the roots of *Abies amabilis*, *A. procera* and *Tsuga mertensiana* in the maritime climatic zone of Oregon and Washington showed that root production in subalpine forests was much larger than that in lowland forests and was larger than that required for water uptake. Up to 65% of ecosystem dry-matter production occurred in the soil. Availability of mineral nutrients appeared to be the main factor responsible for this large investment in fine roots and mycorrhizae.

80 GRIFFIN, J.R.; CRITCHFIELD, W.B. 1972. The distribution of forest trees in California. U.S. For. Serv., Res. Pap. PSW-82, 114 p.

Gives natural distributions of 86 forest and woodland species. Descriptive notes by species cover elevational limits, geographical relationships of species, natural hybridization and intergradation between species and ecological role of species in their communities. Mountain hemlock is distributed from 40°50'N to 36°45'N, and from 1210 m to 3540 m, indicating that it is an important species in the subalpine forest.

81 GRIFFIN, M.S.; SUTHERLAND, J.R.; DENNIS, J.J. 1987. Blight of conifer seedlings caused by *Colletotrichum gloeosporioides*. New For. 1: 81-88.

In a growth-chamber experiment, 70-day-old seedlings of 10 conifer species were inoculated with *C. gloeosporioides* (*Glomerella cingulata*) conidia to determine the host range of the fungus. Based on the percentage of seedlings affected and the disease severity on individual seedlings, the order of most to least susceptible was: western hemlock, *Tsuga mertensiana*, *Larix occidentalis*, Sitka spruce, Engelmann spruce, Douglas-fir (coastal form, then interior form), white spruce and ponderosa pine, lodgepole pine and *Thuja plicata*. The results are discussed in relation to blight management of greenhouse-grown conifer seedlings.

82 HAACK, P.M. 1963. Volume tables for hemlock and Sitka spruce on the Chugach National Forest, Alaska. U.S. For. Serv., Res. Note NOR-4, 2 p.

Tables are based on measurements from 136 trees at least 11.0 in (27.5 cm) dbh in the Prince William Sound area, and on Afognak Island. The Scribner Decimal C rule for 16-ft (4.88 m) logs was used to find board-foot volume of the sample trees. Smalian's formula was used to compute the cubic-foot volume. Volume was found to be largely proportional to D^2H. The inverse of $(D^2H)^2$ was used to weight the equations. Regression analyses showed that: 1) without weighting, most of the curves needed manual adjustment for small tree diameters and log lengths; 2) the inclusion of form class in the array of independent variables proved insignificant to the predictive ability of the equations; and 3) hemlock and spruce data could be pooled.

83 HABECK, J.R. 1967. Mountain hemlock communities in western Montana. Northwest Sci. 41(4): 169-77.

Samples of the trees and saplings in 15 stands were obtained by use of the quarter method and 'importance values' were calculated for each tree species by summing the values for its relative density, frequency and dominance in each stand. Understorey vegetation also was sampled. Irrespective of the composition of pioneer stands, *Tsuga mertensiana* will dominate the stands over a major part of its range in western Montana (the eastern limit of its distribution).

84 HARESTAD, A.S. 1980. Seasonal movement of black-tailed deer on northern Vancouver Island. Diss. Abstr. Int. 40: 5088-5089B.

Columbian black-tailed deer were radio-tagged in a deep-snowfall region on northern Vancouver Island, British Columbia, to determine seasonal movements and habitat use. Deer move seasonally in search of habitats that provide more available energy and nutrients, and a lower risk of predation. The densities of digestible dry matter in amabilis fir-twisted stalk, and mountain hemlock-copperbush associations are comparable with those in the shrub and conifer seral stages. This abundance of deer food in high-elevation habitats suggests that montane forest harvesting will not affect deer populations adversely if food resources at low elevations are maintained.

85 HARRIS, A.S.; FARR, W.A. 1974. The forest ecosystem of southeast Alaska. Forest ecology and timber management. U.S. For. Serv., Gen. Tech. Rep. PNW-25, 109 p.

Reviews timber use from aboriginal to modern cultures, forest species, succession of stands and species, timber-harvesting methods, post-logging residue and stand management. Mountain hemlock occurs throughout southeast Alaska from sea level to timberline. At lower elevations, it is commonly found on the poorer sites on organic soils. Near timberline, mountain hemlock is a major component of forest stands along with Sitka spruce, and it is often found in prostrate or "krummholz" form on alpine meadows above timberline. Growth tends to be slower than that of western hemlock, even on the better sites, and the species does not attain so large a stature. Best development is on well-drained soils where trees 3.8 ft (1.16 m) in diameter and 105 ft (32 m) tall have been reported. Mountain hemlock is equal in shade tolerance to western hemlock, and it reproduces beneath old-growth western hemlock-Sitka spruce stands. Organic soils and rotten wood are suitable seed beds under shade. Mt. hemlock is a less prolific seeder than western hemlock, with crops at roughly the same intervals. Seed averages 114 000 per lb (51 800 per kg). Wing size is roughly the same as that of western hemlock, so dissemination distance is probably less. The wood is comparable to that of western hemlock, and no attempt is made to separate the two species. It is used for dissolving pulp; and because of its slow growth and higher density, it is reported to give higher pulp yields than western hemlock. No attempt is being made to manage mountain hemlock.

86 HAWKSWORTH, F.G.; WIENS, D. 1972. Biology and classification of dwarf mistletoes (*Arceuthobium*). U.S. For. Serv., Agric. Handb. 401. Washington, D.C. 234 p.

This publication covers life cycles, biogeography, host relationships, mechanisms and trends of evolution, systematics and classification criteria. Subgenera *Arceuthobium* and *Vaginata* are used; the latter is divided into three sections: *Vaginata*, *Minuta* and *Campylopoda*; *Campylopoda* is subdivided further into Series *Campylopoda*, *Rubra* and *Stricta*. The subgenus *Arceuthobium* is represented in both the "Old World" (EurAsia) and the "New World" (N and S America), whereas Subgenus *Vaginata* occurs only in the New World. Thirty-two taxa are described and keyed. Descriptions, habit drawings and maps of collections are provided. Coloured photos of many taxa are provided. Mountain hemlock is colonized by *A. tsugense*, which occurs only in coastal areas from lat. 37°N to 59°N. Collections have been made from mountain hemlock as far south as 37°N, in the California Sierras.

87 HAWKSWORTH, F.G.; WIENS, D.; NICKRENT, D.L. 1992. New western North American taxa of *Arceuthobium* (Viscaceae). Novon 2: 204-211.

Several new names are proposed for a taxonomic revision of the dwarf mistletoes (*Arceuthobium* spp.). *A. tsugense* is segregated into two subspecies: subsp. *tsugense* (primarily parasitic on *Tsuga heterophylla*) and subsp. *mertensianae* (primarily parasitic on *T. mertensiana*).

88 HEES, W.W.S. VAN. 1984. Growth rate of western and mountain hemlock on four soil ecosystems in the Petersburg/Wrangell area of southeast Alaska. Pages 225-229 *in* V.J. LaBau and C.L. Kerr (editors). Inventorying forest and other vegetation of the high latitude and high altitude regions. Proc. Int. Symp., Fairbanks, Alaska, 1984. Soc. Am. For., Bethesda, MD, USA.

Observations of the growth rate of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) on four soil ecosystems in the Petersburg/Wrangell inventory unit of southeast Alaska show that elevation and slope had no statistically significant effect on productivity of three of the soils. On one soil ecosystem, elevation had a small but significant negative effect on growth rate. This probably indicates that, as slope increases with elevation, soil drainage changes, climate becomes harsher, and soils become thinner. Increasing elevation may also indicate decreasing soil quality.

89 HEES, W.W.S. VAN. 1988. Timber productivity of seven forest ecosystems in southeastern Alaska. U.S. For. Serv., Res. Pap. PNW-RP-391, 10 p.

Data on the growth of *Chamaecyparis nootkatensis*, *Tsuga mertensiana*, *T. heterophylla*, *Picea sitchensis* and *Thuja plicata* were used to develop regression equations to predict periodic annual volume growth (ft^3) percentage on seven soil types in SE Alaska. Diameter at breast height and percentage of live stocking were used as the independent variables. Aspect was not statistically significant in any equation. Differences in timber productivity were found within and between soil groups.

90 HEIKKINEN, O. 1985. Relationships between tree growth and climate in the subalpine Cascade Range of Washington, U.S.A. Ann. Bot. Fenn. 22:1-14.

The two sites selected for this dendroclimatological study are located on the maritime Mount Baker volcano in Washington State. Precipitation, especially in wintertime, seemed to have a negative correlation with radial growth, whereas most of the monthly mean temperatures were correlated positively with ring width. The Coleman Glacier site is markedly more sheltered than the Easton Glacier site. This is demonstrated by the values for tree growth, sensitivity and autocorrelation in the chronologies (1931-1980).

91 HEMSTROM, M.A.; LOGAN, S.E.; PAVLAT, W. 1987. Plant association and management guide, Willamette National Forest. U.S. For. Serv., Pac. Northwest Reg. R6-Ecol 257-B-86, 312 p.

Data describing plant associations, environmental profiles and productivity are presented for five major series: Douglas-fir, grand fir, Pacific silver fir, western hemlock and mountain hemlock. Four plant associations are described in the mountain hemlock series. Persistent snowpack, cold summers and low soil nutrition are common. Regeneration is irregular and tree growth is slow. Only partial cutting is recommended.

92 HENRY, M.A.; FLOOD, M.G. 1919. The history of the Dunkeld hybrid larch (*Larix eurolepis*) with notes on other hybrid conifers. Proc. R. Irish Acad. 35(B): 55-56.

Instances of hybridization between different species of conifers are not of common occurrence. The rarity of hybrids is explained usually as a result of different natural distributions of the parental species, but overlapping does occur in some genera such as *Tsuga* and *Larix*, and hybrids are still extremely rare. The putative hybrid of *Tsuga mertensiana* and *Tsuga heterophylla*, *Tsuga* X *jeffreyi*, is described in terms of the features it inherited from each parent.

93 HERMAN, F.R.; FRANKLIN, J.F. 1976. Errors from application of western hemlock site curves to mountain hemlock. U.S. For. Serv., Res. Note PNW-276, 8 p.

Eleven dominant and codominant mountain hemlock (*Tsuga mertensiana*) trees, 201-284 yr old, were sampled and in each case, site index was considerably overestimated leading to errors of 60-85% in cu-ft vol and 120-240% in bd-ft vol. Until site-index curves and yield tables are available for *T. mertensiana*, forest managers are advised to develop local ones or reduce estimates found in *T. heterophylla* yield tables.

94 HIBBS, D.E. 1981. Leader growth and the architecture of three North American hemlocks. Can. J. Bot. 59: 476-480.

Height growth in hemlock (*Tsuga canadensis* (L.) Carr., *T. heterophylla* (Raf.) Sarg., *T. mertensiana* (Bong.) Carr.) is by rhythmic growth of a monopodial axis with continuous branch production throughout the growing season. Leader growth is plagiotropic and leader erection is a process lasting several years. Two types of events disrupt the basically monopodial nature of the axis. (1) Frequent (43%) apical meristem death shifts dominance to a nearby lateral branch in *T. canadensis*. (2) Weak apical control allows occasional shifts in dominance from the leader to a branch without meristem death (13 and 24% in *T. heterophylla* and *T. canadensis*, respectively, but none in *T. mertensiana*). These growth patterns contain elements of several tree architectural models but fit none well.

95 HICKMAN, J.C. 1970. Seasonal course of xylem sap tension. Ecology 51: 1052-60.

Xylem-sap tension measurements made during the summer with a pressure chamber on 44 species on herbaceous and woody plants revealed five different patterns of seasonal change. *Juniperus communis* var. *montana* showed the most-common pattern, viz. marked diurnal fluctuations, becoming greater as the season progressed. Actively growing plants exhibiting this pattern withstood tensions >70 atm. *Chamaecyparis nootkatensis*, *Abies amabilis*, *A. procera* and *Tsuga mertensiana* showed seasonally constant or slightly increasing maxima, with minima slowly increasing until there was little diurnal fluctuation. The different responses apparently represent alternative adaptations to a seasonally decreasing moisture supply.

96 HINCKLEY, T.M.; IMOTO, H.; LEE, K.; LACKER, S.; MORIKAWA, Y.; VOGT, K.A.; GRIER, C.C.; KEYES, M.R.; TESKEY, R.O.; SEYMOUR, V. 1984. Impact of tephra deposition on growth in conifers: the year of the eruption. Can. J. For. Res. 14: 731-739.

Seven sites 15-135 km from Mount St. Helens, Washington State, were selected to study the effects of air-fall tephra on the growth of *Abies amabilis*, *A. procera*, *Pseudotsuga menziesii*, *Tsuga heterophylla* and *T. mertensiana* in the months following the eruption of May 1980. As tephra depth increased, there was a corresponding increase in visible foliar damage and associated reductions in diam and ht growth. Coverage of the foliage resulted in foliar damage, foliage abscission and reduction of total tree foliar area, and increased fine-root mortality. Although tephra coverage of the soil had the potential to restrict oxygen diffusion into the soil, soil oxygen concentrations less than 10% were measured only once over a 2-yr period.

97 HOBBS, S.D.; PARTRIDGE, A.D. 1979. Wood decays, root rots, and stand composition along an elevation gradient. For. Sci. 25: 31-42.

Wood-decaying fungi were examined in 74 randomly selected stands of mixed conifers including mountain hemlock. Fungal distributions and stand composition changed with increasing elevation. Infrequently found fungi are tabulated with hosts and clusters.

98 HOPKINS, W.E. 1979. Plant associations of south Chiloquin and Klamath Ranger Districts-Winema National Forest. U.S. For. Serv., Pac. Northwest Reg. R6-Ecol-79-005, 96 p.

Provides a general discussion, a classification concept, a description of community codes and criteria, an elevational gradient of communities, a plant association (site) key, and descriptions of non-forest types and forest types within the 328 300 ac (134 603 ha) Winema National Forest in Oregon. Mountain hemlock is found in the shasta red fir-mountain hemlock/pinemat manganita/long-stolon sedge (between 5200-6500 ft, 1580-1980 m), and the mountain hemlock/grouse huckleberry (between 5700-7500 ft, 1720-2030 m) communities.

99 JACKSON, M.T.; FALLER, A. 1973. Structural analysis and dynamics of the plant communities of Wizard Island, Crater Lake National Park. Ecol. Monogr. 43: 441-461.

Four forest-vegetation types and one non-forest type are described from continuous-belt transects on this 1.27-km^2 volcanic cinder cone in Crater Lake, Oregon. Dominant tree species were: *Pinus albicaulis* in the scattered stand round the summit crater, and various combinations of *Abies magnifica* var. *shastensis*, *Tsuga mertensiana* and *Pinus* *monticola* in the three other forest areas. Details are given of climate, soils and vegetation. Graphs are plotted showing survival of the tree species in the four forest communities.

100 JOHNSON, G.P. 1980. Site index equations for mountain hemlock on three habitat types in the central Oregon Cascades. MS Thesis, Oreg. State Univ., Corvallis, OR. 56 p.

Site index and height growth equations for mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) were developed from 37 trees located in the Deschutes National Forest. Recommendations for the application and interpretation of the equations are presented.

101 KANDYA, A.K.; OGINO, K. 1986. Reserve dry weight of seed: a significant factor governing the germination potential of seeds in some conifers. J. Trop. For. 2: 21-26.

Seeds of 12 species, including *T. mertensiana*, were weighed and those with matching weight within species were paired. One seed of each pair was sown in volcanic ash and germination recorded. The other seeds were oven dried for 24 h, the seed coat removed and both coat and seed re-weighed. The reserve dry weight (RDW = dry weight of seed minus dry weight of seed coat) was found to be more strongly correlated with the number of days to germination than total seed weight. Correlation coefficients varied from -0.97 to -0.71 from RDW and from -0.92 to -0.59 for seed weight. Regression equations are given for each species. The seed coat was found to weigh 16-60% of the total seed weight. Intraspecific differences between max and min seed weight were particularly large in *P. strobus* and *P. radiata*.

102 KELLOGG, R.M.; ROWE, S. 1981. An anatomical method for differentiating woods of western hemlock (*Tsuga heterophylla*) and mountain hemlock (*Tsuga mertensiana*). Wood Fiber 13(3): 166-168.

Styloid crystals composed of calcium oxalate were found in ghost or tracheary cells marginal to rays in the last-formed latewood of all mountain hemlock trees, but only in two of 40 western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) trees studied. The presence of styloid crystals in two or more radial sections per tree can be used to confirm mountain hemlock; crystals in zero or one indicate western hemlock.

103 KENNY, N. 1976. An inquiry into hybridization between *Tsuga heterophylla* and *Tsuga mertensiana*. B.S. Thesis, Dep. Sci., Univ. B.C., Vancouver, B.C. 39 p. plus appendices.

Cones and foliage were collected from three areas (Mt. Seymour, Diamond Head and Mt. Revelstoke) in British Columbia and analysed for morphological intermediacy, using principal components analysis based on nine vegetative characters and a general ratio comparison of lengths and widths of cones and needles. No hybridization was evident. Mountain hemlock became more like western hemlock with increasing elevation when length:width ratios of cones and needles were considered. Mountain hemlock became more like western hemlock with decreasing elevation when eigenvector 1 was compared to elevation. Where the two species overlapped, there was greater dissimilarity than where they occurred separately. Greatest dissimilarity occurred on Mt. Seymour; similarity increased progressively at Diamond Head and Mt. Revelstoke, respectively. Reasons for these trends are discussed.

104 KLINKA, K.; FELLER, M.C. 1984. Principles used in selecting tree species for regeneration of forest sites in south western British Columbia. For. Chron. 60: 77-85.

Species are selected based on ecological characteristics of the site and whether they meet criteria of maximal sustainable productivity, crop reliability and silvicultural feasibility. Mixed species are appropriate to all but the driest, wettest and lowest-nutrient sites. Mountain hemlock and amabilis fir are recommended in the wetter maritime subalpine-boreal or montane maritime mesothermal climates.

105 KLINKA, K.; GREEN, R.N.; COURTIN, P.J.; NUSZDORFER, F.C. 1984. Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest Region. Land Manag. Rep. 25, B.C. Min. For., Victoria. 180 p.

Site diagnoses are presented based on indicator species, topographic and soil characterization. Selection of appropriate tree species for reforestation is based on ecological and management factors, and on maximal sustainable productivity, crop reliability and silvicultural feasibility. Mountain hemlock occurs in the Parkland, Maritime Forested and Submaritime Forested subzones. Moisture-class and nutrient-class grids, displaying recommended tree species, are presented. Potential slashburning effects on regeneration and early growth are outlined.

106 KLINKA, F.; NUSZDORFER, F.C.; SKODA, L. 1979. Biogeoclimatic units of central and southern Vancouver Island. B.C. Min. For., Vancouver, B.C. 120 p.

Mountain hemlock is usually shallow rooted and, in British Columbia, its roots are mainly confined to the organic layer. In coastal areas of B.C., wind commonly destroys mountain hemlock trees.

107 KLINKA, K.; POJAR, J.; MEIDINGER, D.V. 1991. Revision of biogeoclimatic units of coastal British Columbia. Northwest Sci. 65(1): 32-47.

Tabular and multivariate analyses using subsets of 1299 samples of alpine, subalpine, montane, and submontane, zonal climax vegetation resulted in a revision and refinement of the biogeoclimatic units for coastal British Columbia originally proposed by Krajina and modified by subsequent workers. The revision conserved the existing four biogeoclimatic zones (Coastal Douglas-fir, Coastal Western Hemlock, Mountain Hemlock, and Alpine Tundra) but increased the number of subzones from two to ten in the Coastal Western Hemlock zone, from two to four in the Mountain Hemlock zone and reduced the number of subzones from two to one in the Coastal Douglas-fir zone. Diagnostic tables, climatic summaries and ordination results are presented to show relationships among the zones and subzones. Climatic data suggest that the four zones, each characterized by a unique climatic type, represent major segments of the regional temperature gradient, while subzones reflect division of this gradient according to continentality, precipitation, and temperature.

108 KNUTSON, D.M.; TINNIN, R.O. 1981. *Arceuthobium cyanocarpum* (limber pine dwarf mistletoe) in Oregon: *Pinus albicaulis* and *Tsuga mertensiana*. Plant Dis. 65(9): 445.

This report documents the occurrence of *Arceuthobium cyanocarpum* infections on *Tsuga mertensiana* in Oregon. The infected trees were found in the same stands as infected *Pinus albicaulus* in a small area of approximately 100 ha.

109 KOERBER, T.W. 1963. *Leptoglossus occidentalis* (Hemiptera, Coreidae), a newly discovered pest of coniferous seed. Ann. Entomol. Soc. Am. 56(2): 229-34.

The insect was found on cones and male strobili of Douglas-fir from British Columbia to Mexico. It causes seeds to shrink. It could be reared on numerous species including mountain hemlock.

110 KOPPENAAL, R.S.; MITCHELL, A.K. 1992. Regeneration of montane forests in the Coastal Western Hemlock Zone of British Columbia: a literature review. Can./B.C. For. Resource Dev. Agreement (FRDA), Rep. No. 192, Gov. Can./Province of B.C., 22 p.

Problems in the regeneration of coastal montane ecosystems are discussed under: 1) climatic conditions, 2) species selection, and 3) harvesting methods and site preparation. Natural regeneration can be well suited for restocking montane stands but may not meet growth expectations as a result of site disturbance. Advance regeneration is subject to problems associated with disturbance of the forest floor and the seedbed during stand removal. Artificial regeneration also can be used to achieve adequate stocking levels in stands where natural regeneration is poor or patchy. The selection of artificial or natural regeneration is modified by the type and severity of environmental and biological stresses that occur after exposure. Small clearcuts (less than 8 ha) and shelterwood cuttings are considered the most consistently successful systems for even-aged management of montane and subalpine true fir-hemlock forests in the Pacific Northwest.

111 KRAJINA, V.J. 1969. Ecology of forest trees in British Columbia. Ecology of western North America 2: 1-147. Dept. Bot., Univ. B.C., Vancouver, B.C.

On the east side of the Coast Mountains in British Columbia, mountain hemlock is limited to relatively moist sites where snow accumulates early in the fall. It does not grow on sites with later, thinner, snowpacks because it cannot tolerate the frozen soils there. Site index (base age 100 yr) ranges from less than 6 m (20 ft) on xeric sites to 34 m (110 ft) on the best sites. Although it pioneers on glacial moraines in B.C. and Alaska, it is nevertheless considered indicative of the climax forest.

112 KRAJINA, V.J.; KLINKA, K.; WORRALL, J. 1982. Distribution and ecological characteristics of trees and some shrubs of British Columbia. Univ. B.C., Fac. For., Vancouver, B.C. 131 p.

Thirty-five tree species, including mountain hemlock, and eleven shrub species native to B.C. are characterized by their geographic distribution, climatic requirements, orographic position, physiognomic type, edatopic requirements, nutritional type, and the biogeoclimatic unit in which each occurs. Tolerance to frost, shading and flooding are integrated also into brief discussions of ecological requirements and silvicultural importance. Mountain hemlock (p. 61-63) is more frost resistant than western hemlock, and has similar shade tolerance (high) and flood resistance. Its nutritional requirements are low.

113 KURTH, E.F. 1967. The chemical composition of conifer bark waxes and corks. TAPPI 50: 253-8.

The bark wax of mountain hemlock differed from that of Douglas-fir and white fir, but the corks of all three were of similar composition.

114 LITTLE, E.L., JR. 1979. Checklist of United States trees (native and naturalized). U.S. Dep. Agric., Agric. Handb. 541. Washington, D.C. 375 p.

Compiles accepted scientific names and synonyms, approved common names and others in use. Gives the ranges of native and naturalized trees of the U.S. (including Alaska). Mountain hemlock (p. 425-426) was named for K.H. Mertens, who discovered it at Sitka, Alaska.

115 LOHWAG, K. 1950. Bienenwabenfäule, hervorgerufen durch *Phellinus nigrolimitatus* (Romell) B. et G. [Honeycomb rot caused by *Phellinus nigrolimitatus*.] Mitt. Österr. Ges. Holzforsch 2: 22-4. (In German).

This fungus, which is described in detail, occurs widely in the higher regions of the Alps, and causes the little-known 'honeycomb' rot in spruce wood. The fungus attacks mountain hemlock, western hemlock, pine, fir, larch, Douglas-fir and *Thuja*.

116 LOWERY, R.F. 1972. Ecology of subalpine zone tree clumps in the North Cascade Mountains of Washington. Diss. Abstr. Int. 33: 1876B-1877B.

A survey of tree-clump characteristics and associated environmental factors indicated that tree clumps occur most frequently on slight topographic rises. *Abies lasiocarpa* was most abundant in clumps on the driest, most-inhospitable sites; *Tsuga mertensiana* was most important on wet, cool sites; *A. amabilis* was most common in clumps in low-lying moist areas; and *Chamaecyparis nootkatensis* was found in a few clumps on moist sites at low elevations. Clump height was negatively correlated with degree of slope, elevation and radiation index. Examination of two clumps showed that they had expanded radially around the first trees established at the site, and that clump expansion has been paralleled by an improvement in climate that began ca 300 yr ago. Environmental factors affecting germination and seedling survival of the species are investigated and discussed.

117 MACDONALD, J.; WOOD, R.F.; EDWARDS, M.V.; ALDHOUS, J.R. (EDS.) 1957. Exotic forest trees in Great Britain. For. Comm. Bull. 30: 136-140. London, HMSO.

Ten known species of hemlock, plus one natural hybrid (X *T. jeffreyi*, considered to be a cross between *T. mertensiana* and *T. heterophylla*) are described briefly. Emphasis is placed on *T. heterophylla*, the only *Tsuga* species, with the possible exception of *T. mertensiana*, that is of any economic importance in Great Britain.

118 MASER, C.; MASER, Z. 1988. Interactions among squirrels, mycorrhizal fungi, and coniferous forests in Oregon. Great Basin Nat. 48(3): 358-369.

Mycophagy (ingestion of fungi) was examined for five genera and eight species of squirrels in the coniferous forests of Oregon. The squirrels were taken from five forest types: 1) western hemlock (*Tsuga heterophylla*), 2) mixed conifer and mixed-evergreen, 3) subalpine forest (*Abies amabilis/A. lasiocarpa/T. mertensiana*), 4) ponderosa pine (*Pinus ponderosa*) and 5) grand fir/Douglas-fir (*A. grandis/Pseudotsuga menziesii*). Data from 644 dietary samples showed that squirrels of all eight species were mycophagous and ate the below-ground fruiting bodies of at least 26 genera of mycorrhizal fungi. *Rhizopogon* was the dominant genus in all squirrel diets. The flying squirrel was used to illustrate the dynamics of squirrels in association with hypogeous mycorrhizal fungi, nitrogen-fixing bacteria, yeast and coniferous trees in Oregon forests.

119 MATHIASEN, R.L.; HAWKSWORTH, F.G. 1988. Dwarf mistletoes on western white pine and whitebark pine in northern California and southern Oregon. For. Sci. 34(2): 429-440.

Western white pine (*Pinus monticola*) is infected occasionally by dwarf mistletoe (*Arceuthobium tsugense*) found in stands of *Tsuga mertensiana* in California and southern Oregon. However, no infection of western white pine occurred in *A. tsugense*-infected western hemlock stands in southern Oregon. This report indicates that there may be physiologically distinct races of *A. tsugense* parasitizing these two species of hemlock: one that has mountain hemlock as its primary host and western white pine as an occasional host, and the other that has western hemlock as its only host. Furthermore, artificial inoculations, with *Arceuthobium tsugense* seeds from western and mountain hemlock on western hemlock, have produced successful infections only from seeds collected on western hemlock.

120 MATSON, P.A.; BOONE, R.D. 1984. Natural disturbance and nitrogen mineralization: wave-form dieback of mountain hemlock in the Oregon Cascades. Ecology 65(5): 1511-1516.

Wave-form dieback of relatively pure stands of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) due to *Phellinus weirii* in the Oregon Cascades was studied. Nitrogen-mineralization rates of forest floor and mineral soil were estimated using laboratory and *in situ* incubations. Nitrogen-mineralization rates in both the mineral soil and the 0_2 horizon were at least doubled following the pathogen-induced disturbance. As the regenerating stands developed, rates declined again to the very low predisturbance levels. These changes in nitrogen availability may in turn influence tree resistance to the pathogen, since, under controlled conditions, N nutrition substantially influences the extent of foliage damage and loss in mountain hemlock seedlings that were inoculated with *Phellinus*. The mortality of old-growth trees at the wave front could be influenced by low N availability; the higher availability in the regrowth could explain why trees are not killed despite the presence of *Phellinus* in dead roots and stumps. Therefore, this system suggests that the pattern of nitrogen availability is both a consequence and a cause of natural disturbance.

121 MATSON, P.A.; WARING, R.H. 1984. Effects of nutrient and light limitation on mountain hemlock: susceptibility to laminated root rot (*Phellinus weirii*). Ecology 65(5): 1517-1524.

Pure stands of *Tsuga mertensiana* in Oregon were found to exhibit wave-form dieback caused by *Phellinus weirii* infections. It was discovered that many regenerating *T. mertensiana* forests do not readily become re-infected with root rot. It was concluded that a higher concentration of nitrogen and other nutrients in the regenerating forests may have caused this resistance ability. Small trees were tested with treatments of nitrogen, phosphorus and nonstructural carbohydrates. These trees subsequently became more resistant to *Phellinus weirii*. Shaded trees had low resistance and exhibited foliar damage, even with added nutrients.

122 MCCAULEY, K.J.; COOK, S.A. 1980. *Phellinus weirii* infestations of two mountain hemlock (*Tsuga mertensiana*) forests in the Oregon Cascades. For. Sci. 26: 23-29.

The *Phellinus weirii* infection centres in two mountain hemlock stands were examined for resistant trees that were discriminated by size and age from adjacent regrowth trees. The rate of spread of *Phellinus weirii* and relative resistance of trees on the basis of escape frequency were determined at ten infection centres in each stand. In stands with mixed conifers the spread of *Phellinus* was less than in stands with dominant mountain hemlock. Mountain hemlock therefore has the least resistance. Mortality caused by fungus results in diversity, but it is also evident that variety stops the spread of infection.

123 MCNAB, W.R. 1877. Remarks on the structure of the leaves of certain Coniferae. Proc. R. Irish Acad., ser. 2, 2: 209-213.

Based on leaf anatomy, six species of *Tsuga* (*hookeriana, pattoniana, canadensis, mertensiana, brunoniana* and *sieboldii*) are separated in a key. There is no mention of *Tsuga heterophylla*, and this may be the author's *T. canadensis*. Mountain hemlock apparently is named *T. hookeriana*.

124 M'NAB, W.R. 1882. Note on *Abies pattonii*, Jeffrey MMS., 1851. Linn. Soc. J. Bot. 19: 208-212.

Describes problems in naming of mountain hemlock. (According to Farjon (1990), *Abies pattoniana* = *Tsuga mertensiana*, while *Abies hookeriana* = *Tsuga mertensiana* ssp. *grandicona*; see also Farjon 1988.)

125 MEAGHER, M.D. 1976. Studies of variation in hemlock (*Tsuga*) populations and individuals from southern British Columbia. Diss. Abstr. Int. 37: 3176B.

Morphological, physiological and reproductive differences between *Tsuga mertensiana* and *T. heterophylla* indicate their genetic distinctness. Attempts at cross-pollinating these species were unsuccessful. Possible evolutionary reasons for the diversity found in *Tsuga* are suggested.

126 MEANS, J.E. 1990. *Tsuga mertensiana*-mountain hemlock. Silvics of North America. U.S. Dep. Agric., Agric. Handb. 654(1): 623-634. Washington, D.C.

This report describes the climate, range, soils, topography, associated forest cover, lifecycle, economics, ecology and pathogens of *Tsuga mertensiana* forests. Morphological traits of *Tsuga mertensiana* are compared with other species of conifers. Hybrids and genetic diversity are discussed.

127 MEANS, J.E.; CAMPBELL, M.H.; JOHNSON, G.P. 1988. Preliminary height-growth and site-index curves for mountain hemlock. FIR Rep. 10(1): 8-9.

Ninety-five undamaged trees in unmanaged stands were sampled from the southern Oregon Cascades to the southern Washington Cascades. Best height growth of mountain hemlock was achieved in mixed stands on warmer sites.

128 MILLER, D.J. 1961. Oregon woods for crossties. For. Prod. J. 11: 579-82.

Sleepers of nine conifer species and Tanoak (*Lithocarpus densiflorus*) that had been air-dried and pressure treated with coal-tar creosote in petroleum, were subjected to main line service tests for 4 to 11 yr. Various defects due to seasoning and mechanical wear developed, but there was no decay. Mountain hemlock and lodgepole pine were the most severely checked.

129 MILLER, D.J.; HOUGHTON, P.R. 1981. Performance of western wood species as crossties in mainline railroad track. For. Prod. J. 31(5): 51-58.

Crossties (sleepers) of nine Oregon wood species are being tested (and compared with Douglas-fir) in mainline railroad tracks in California, Oregon and Arizona. Climatic conditions and topography vary widely among the sites where ties have served for the past 27 yr. The ties have been inspected periodically and their condition noted for checking and wear that might affect service life. All had been similarly prepared and pressure-treated with a creosote-petroleum solution. Ties that were in good condition or were only moderately checked when inserted have usually been longer lasting than those that initially were split or badly checked. Platecutting, wide checks, and splits have been common defects in ties that have had to be renewed. Other defects including decay are still generally uncommon. Ties of incense cedar (*Libocedrus decurrens*), lodgepole pine, Shasta fir (*Abies magnifica*), western hemlock, and tanoak (*Lithocarpus densiflorus*) were as durable as those of Douglas-fir. Some of the other species being tested may perform as well but need further evaluation. Mountain hemlock usually showed the most defects at first inspection, ranked last in percentage of good new ties (30%), displayed cross grain, and some twist of higher frequency, and showed average (24%) failure of those tested only 20-24 yr.

130 MILLER, G.E.; RUTH, D.S. 1989. The relative importance of cone and seed insect species on commercially important conifers in British Columbia. Pages 25-34 *in* G. Miller (compiler). Proc. of the 3rd Cone and Seed Insects Working Party Conf., Victoria, B.C., Canada, June, 1988. For. Can., Pac. For. Cent., Victoria, B.C.

The results of an on-going survey of cone and seed insect pests in British Columbia are reported. Of 11 conifers that had damage, *Pinus contorta*, *Tsuga heterophylla* and *T. mertensiana* suffered minimal losses. The common cone and seed insect species and the relative importance of each are indicated for each species of conifer.

131 MINORE, D. 1979. Comparative autecological characteristics of northwestern tree species - a literature review. U.S. For. Serv., Gen. Tech. Rep. PNW-87, 72 p.

A full description of morphology, physiology, reproduction and growth requirements of 40 native species, including *Tsuga mertensiana*, is provided. Data on the sensitivity of *Tsuga mertensiana* to chemicals such as herbicides and salt are given. Resistance to insects, diseases, and climate for each tree species is described.

132 MINORE, D.; DUBRASICH, M.E. 1981. Regeneration after clearcutting in subalpine stands near Windigo pass, Oregon. J. For. 79(9): 619-621.

An analysis of natural reforestation after clearcutting showed that a period of 9 to 12 yr is required for successful natural regeneration of clearcuts and that *Tsuga mertensiana* was one of the species that regenerated at a faster rate in subalpine areas.

133 MORAL, R. DEL. 1973. The vegetation of the Findley Lake Basin. Amer. Mid. Natur. 89(1): 26-40.

A description of the vegetation communities of Findley Lake Basin, Washington, includes the rare *Tsuga mertensiana* community type. The ecosystems of the different communities were analysed in terms of biological and physical components such as: elevation, canopy cover, moisture level, slope, soil type, wildlife, and associated vegetation that exemplify each forest type. A preserved mountain hemlock community is considered useful as a model for management practices as it provides an opportunity to study intact vegetation free from disturbances associated with logging, fishing, hunting, or recent forest fires. Different rates of forest development were observed and this type of model is proposed to help preserve plant communities that are threatened by development.

134 MORAVETS, F.L. 1941. Forests of the Willamette: the resource. West Coast Lumberm. 68: 26, 28.

Based on the 1933 inventory, saw-timber-sized mountain hemlock is found in mixed woods (western hemlock, Pacific silver fir, western white pine and Alaska yellow cedar) that cover some 360 000 ac (146 000 ha). Douglas-fir predominates on 82% of the stocked forest land.

135 MUNZ, P.A.; KECK, D.D. 1970. A California flora. Univ. Calif. Press., Berkeley. 1681 p., supplement, 224 p.

Includes detailed descriptions of foliage, strobili, cones, seeds and habitats to distinguish *Tsuga mertensiana* from *T. heterophylla*.

136 MURRAY, A. 1850. Botanical expedition to Oregon. No. 2. Pamphlet (3 p. + 5 figs.). Edinburgh.

Provides a list of the plants (specimens or seeds) collected by J. Jeffrey. Mountain hemlock is identified as *Abies pattoniana*.

137 MURRAY, A. 1855. Description of new coniferous trees from California. Edinb. New Philos. J. 1: 284-295.

Describes six "new" species based on foliage and twigs, cones, scales, bracts and wings. Mountain hemlock is identified as *Abies hookeriana* (=*Tsuga mertensiana* ssp. *grandicona* Farjon) or *A. pattoniana* (=*T. mertensiana* ssp. *mertensiana* Farjon).

138 NEILAND, B.J. 1971. The forest bog complex of southeast Alaska. Vegetatio 22: 1-64.

Drainage, rather than slope, was the dominant factor in bog development. In ecotone forests with increasingly poor drainage, the trees were smaller, with an increasing proportion of *Chamaecyparis nootkatensis*, *Thuja plicata* and *Tsuga mertensiana*. *Tsuga heterophylla* was the most abundant tree in forests and ecotones. Tree establishment on bogs depended on favourable seasons, which occurred very infrequently. The general pattern of vegetation and the frequency of dead trees suggested that drainage and other habitat factors were changing continually.

139 NELSON, E.E.; FAY, H.A. 1975. Effect of temperature on growth and survival of high- and low-elevation isolates of *Phellinus* (*Poria*) *weirii*. Northwest Sci. 49: 119-121.

Isolates of *Poria weirii* from *Tsuga mertensiana* trees at altitudes above 1675 m and from *Pseudotsuga menziesii* trees at altitudes below 488 m did not differ significantly in growth or survival under various temperature regimes in the laboratory.

140 NICKRENT, D.L.; STELL, A.L. 1990. Electrophoretic evidence for genetic differentiation in two host races of hemlock dwarf mistletoe. Biochem. Syst. Ecol. 18(4): 267-280.

The results of a starch-gel-electrophoresis study of three suspected races of *Arceuthobium tsugense* showed that the races did not readily parasitize their non-preferred host, and that the mountain hemlock race was the most distinct race of hemlock dwarf mistletoe.

141 OWENS, J.N. 1984. Bud development in mountain hemlock (*Tsuga mertensiana*). I. Vegetative bud and shoot development. Can. J. Bot. 62(3): 475-483.

Vegetative buds of mature *Tsuga mertensiana* were studied during the annual growth cycle. An extensive description of morphological and physiological changes during the cycle is given. The relationship between bud development and shoot development is discussed for *Tsuga mertensiana* and other conifer species.

142 OWENS, J.N. 1984. Bud development in mountain hemlock (*Tsuga mertensiana*). II. Cone bud differentiation and predormancy development. Can. J. Bot. 62(3): 484-494.

Seed and pollen cones were studied during the annual growth cycle of *Tsuga mertensiana*. A detailed description is given of the morphological and physiological changes, and the sequence in which they occur during the cycle. Differentiation of cone buds is compared to *Tsuga heterophylla* and other conifers with similar bud development cycles.

143 OWENS, J.N.; BLAKE, M.D. 1983. Pollen morphology and development of the pollination mechanism in *Tsuga mertensiana* and *Tsuga heterophylla*. Can. J. Bot. 61(12): 3041-3048.

Tsuga mertensiana was determined to be the only *Tsuga* species possessing saccate pollen. The pollination mechanism differs from that of *Tsuga heterophylla*, also described in this study. A possible phylogenetic scheme for *T. mertensiana*, based on pollen morphology data, is discussed.

144 OWENS, J.N.; MOLDER, M. 1975. Sexual reproduction of mountain hemlock (*Tsuga mertensiana*). Can. J. Bot. 53: 1811-1826.

Meiosis of pollen mother cells begins in October of the year in which cones are initiated. They reach pachytene, then become dormant until the next March. Meiosis is complete and the winged pollen matures by mid-June. Meiosis of the megaspore mother cell occurs in May and the female gametophyte undergoes free-nuclear division at pollination in mid-June. Pollen adheres to the sticky, splayed edge of the micropyle, where it germinates; pollen tubes grow toward the nucellus. Fertilization occurs early in August. The embryo and seed are mature in October and the cones dry and open during October and November. Reproduction is similar to that in other species of *Tsuga*, except for the presence of winged pollen. Its classification relative to *Picea* and *Tsuga* is discussed.

145 OWENS, J.N.; MOLDER, M. 1984. The reproductive cycles of western and mountain hemlock. B.C. Min. For., Victoria, B.C. 34 p.

A detailed description of the reproductive cycles of *Tsuga mertensiana* and *Tsuga heterophylla* is given. The two *Tsuga* species are discussed in terms of their taxonomy, distribution, habitat, economic importance, reproductive potential, vegetative reproduction, and reproductive phenology. Vegetative bud and shoot development, differentiation of bud types, and the pathways of bud development are described. The sequence of events, their chronology, and the morphology of the buds are detailed. Activities such as enhancing cone-bud differentiation, identifying buds, and forecasting cone crops are illustrated. Practices such as cone collection, seed extraction, seed storage, and germination are mentioned as methods of enhancing and controlling cone and seed production for reforestation. The hybrid origin of *Tsuga mertensiana* is discussed briefly.

146 PAGE, C.N. 1988. New and maintained genera in the conifer families Podocarpaceae and Pinaceae. Notes R. Bot. Gard. Edinb. 45: 377-395.

The possible affinities and taxonomic status of some smaller taxa are considered. It is proposed that *Cathaya*, *Nothotsuga* and *Hesperopeuce* should be looked upon as separate genera, although each has some affinity with *Tsuga*. The affinity between *Tsuga* and *Picea* is discussed also. Mountain hemlock is named *Hesperopeuce mertensiana* (Bong.) Rydb. "Intergeneric hybrids" between *H. mertensiana* and *Tsuga* are called X *Hesperotsuga*, with the following crosses described: X *H. jeffreyi* (*Tsuga* X *jeffreyi;*), or *T. mertensiana* var. *jeffreyi*, or *T. pattoniana* var. *jeffreyi*.

147 PARKER, A.J. 1988. Stand structure in subalpine forests of Yosemite national park. For. Sci. 34(4): 1047-1058.

The stand structure of subalpine forests was used to study the pattern of growth, establishment and tolerances of *Tsuga mertensiana* seedlings. Seedling densities and diameter-class distributions were analyzed in comparison to other conifer species present in the subalpine areas studied. The population dynamics of *Tsuga mertensiana* in natural conditions is discussed in relevance to logging impacts.

148 PARSONS, D.J. 1972. The southern extensions of *Tsuga mertensiana* (mountain hemlock) in the Sierra Nevada. Madroño. 21(8): 536-539.

The distribution and habitat preference of the most southerly extensions of *Tsuga mertensiana* are documented. The southern components of the mountain hemlock forests are confined to scattered stands at elevations above 9000 ft in the southern Sierra Nevada of California, extending as far south as Silliman Creek, Sequoia National Park. Topographical variables that influence the southernmost distribution are aspect and elevation. Soils were loose, coarse-textured, covered with undergrowth, and maintained moderate amounts of water throughout the summer. In these stands, there is a large number of healthy juvenile trees in each of the sites studied; reproduction is vigorous, but there are no pure stands of mountain hemlock.

149 PETERSON, E.B. 1964. Plant associations in the subalpine mountain hemlock zone in southern British Columbia. Diss. Abstr. 25: 2193.

The vegetation of the Subalpine Mountain Hemlock Zone was studied on 130 sample plots near Vancouver and Garibaldi, B.C. This report describes 14 plant associations from two altitudinal subzones of the Subalpine Zone that are determined mainly by intensity, quantity and duration of snow.

150 PFISTER, R.D.; KOVALCHIK, B.L.; ARNO, S.F.; PRESBY, R.C. 1977. Forest habitat types of Montana. U.S. For. Serv., Gen. Tech. Rep. INT-34, 174 p.

Mountain hemlock occurs in the *Abies lasiocarpa* series which is subdivided into three elevational categories: 1) lower subalpine containing *Tsuga mertensiana/Menziesia ferruginea* and 2) *Tsuga mertensiana/Xerophyllum tenax* habitat types, upper subalpine containing the *Tsuga mertensiana/Luzula hitchcockii* habitat type, and 3) timberline. There are no *Tsuga mertensiana* habitat types. For each habitat type, distribution in Montana, vegetation, soil, productivity and management features are considered. *Tsuga mertensiana*, along with *Abies lasiocarpa*, *Pinus albicaulis* and *Larix lyallii*, are potential climax dominants.

151 PRAGER, E.M.; FOWLER, D.P.; WILSON, A.C. 1976. Rates of evolution in conifers (*Pinaceae*). Evolution 30(4): 637-649.

Comparative immunological and amino-acid-sequence studies of proteins were used to derive possible phylogenetic relationships between members of the family Pinaceae. Structural-gene evolution in Pinaceae was found to have evolved at roughly the standard rate, but karyotypic, or chromosomal, evolution proceeded unusually slowly. The slow anatomical evolution in Pinaceae can perhaps be ascribed to their remarkably slow karyotypic evolution. An antigenic distance of 1.0 places *Tsuga mertensiana* and *Tsuga heterophylla* in separate sections, as they are relatively distant from each other in relation to other species within the coniferous genera, such as *Larix*, which has an antigenic distance of 0. A suggested phylogenetic tree for eight Pinaceae genera was constructed.

152 RAPHAEL, M.G.; MORRISON, M.L. 1987. Decay and dynamics of snags in the Sierra Nevada, California. For. Sci. 33: 774-783.

Snag populations were sampled during 1975-78 and in 1983 on two plots in an area dominated by a second-growth forest of *Pinus jeffreyi* and *Abies concolor* with *A. magnifica* and *Tsuga mertensiana* at higher alt, and *Populus tremuloides* and *Pinus contorta* on mesic sites. Analysis of rates of decay, falling and recruitment showed that large-diam (>38 cm dbh) snags fell more slowly than smaller snags. All needles and twigs fell from snags within 5 yr and most larger branches were lost within 5 yr by 75% of pines and 66% of firs. Rates of mortality were highest for *P. jeffreyi* of 13-15 cm dbh. During the study, mortality exceeded the rate at which snags fell. A Leslie matrix model was developed to describe the dynamics of the snag population.

153 RAU, G.H. 1978. Conifer needle processing in a subalpine lake. Limnol. Oceanogr. 23: 356-358.

The decay of needles of Pacific silver fir (*Abies amabilis*) and mountain hemlock (*Tsuga mertensiana*) was followed in the littoral zone of Findley Lake, Washington, which is surrounded by forest of these species. The needles lost 80-90% of their initial dry wt. during the 1st yr of incubation; there was little further loss during the 2nd yr. The decay rate observed was similar to published results for needle decay in streams in the Pacific Northwest, suggesting that biological, rather than physical, factors were important.

154 ROCHEFORT, R.M.; LITTLE R.L.; WOODWARD, A.; PETERSON, D.L. 1994. Changes in sub-alpine tree distribution in western North America: a review of climatic and other causal factors. The Holocene 4: 89-100.

Based on studies representing three climatic zones (maritime, Mediterranean, continental), recent invasions of subalpine meadows by forest have been associated with climatic periods favoring germination and growth, although factors such as fire and grazing by domestic livestock have had an impact in some areas. For mountain hemlock (and subalpine fir), invasion into heather communities on topographic convexities, the soils of which were more xeric than surrounding depressions, has been attributed to low snow accumulation, moderate spring and early-summer temperatures, earlier snowmelt, longer growing seasons and large seed crops.

155 RUDLOFF, E. VON. 1975. Chemosystematic studies in the genus *Tsuga*. Leaf and twig oil analysis of western hemlock. Can. J. Bot. 53(9): 933-939.

Analysis of the chemical composition of leaves and twigs of *Tsuga heterophylla* was used to determine variation in populations and variation caused by other factors. Possible analysis for *Tsuga heterophylla-Tsuga mertensiana* hybrids is discussed.

156 RUDLOFF, E. VON. 1975. Volatile leaf oil analysis in chemosystematic studies of North American conifers. Biochem. Syst. Ecol. 2: 131-167.

Results of leaf-oil analyses were used to discuss possible relations between species of *Tsuga* and with other genera of conifers. Samples from 10 trees of each species of *Tsuga* were analyzed and *Tsuga mertensiana* was found to have a leaf-oil composition intermediate between *T. heterophylla* and *T. canadensis*. No similarity between *T. mertensiana* and *Picea* was found. The differences in composition between *T. mertensiana* and *T. heterophylla* were large enough to detect hybrids, but this was not determined experimentally.

157 RUDLOFF, E. VON; LAPP, M.S. 1989. Some observations on the leaf oil analysis of mountain hemlock, *Tsuga mertensiana*. Can. J. For. Res. 19(7): 848-852.

The leaf-oil terpene composition of mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.) from eight central-coastal, three interior, and three southern populations, as well as within-tree variation, was studied. High intra- but low inter-population variation was found. No significant elevational differences were recorded. Most trees from the southern populations had lower car-3-ene and higher alpha-pinene and beta-phellandrene percentages than those from northern locations. Interior populations did not differ extensively from coastal populations. Owing to the high tree-to-tree variability, putative hybridization of mountain hemlock with western hemlock would be difficult to detect by leaf-oil terpene analysis.

158 RUNDEL, P.W.; PARSONS, D.J.; GORDON, D.J. 1977. Montane and subalpine vegetation of the Sierra Nevada and Cascade Ranges. Pages 559-599 *in* M.G. Barbour and J. Major (eds.). Terrestrial vegetation of California. John Wiley, New York.

Where mountain hemlock grows in the central Sierra Nevada, the growing season is short, from 49 to 63 frost-free days. It is found less frequently on organic soils (histosols) in the southern portion, than in the northern portion, of its range.

159 RUTH, R.H. 1975. *Tsuga* (Endl.) Carr. - Hemlock. Pages 819-827 *in* C.S. Schopmeyer (tech. coord.). Seeds of woody plants of the United States. U.S. Dep. Agric., Agric. Handb. 450. Washington, D.C. 883 p.

The morphology of cones and seeds, flowering and fruiting data are described. This chapter discusses seed extraction, germination and nursery practices.

160 RYDBERG, P.A. 1912. Studies on the Rocky Mountain flora-XXVI. Bull. Torrey Bot. Club 39: 99-111.

Recommends changes in nomenclature for *Tsuga mertensiana* (a.k.a. *Pinus mertensiana, Abies mertensiana, A. pattoniana, Tsuga pattoniana* or *Hesperopeuce pattoniana*) to *H. mertensiana*. Nomenclature sources are provided.

161 SCAGEL, R.; GREEN, R.; VON HAHN, H.; EVANS, R. 1989. Exploratory high elevation regeneration trials in the Vancouver Forest Region: 10-year species performance of planted stock. Canada/B.C. For. Resource Dev. Agreement (FRDA) Rep. No. 098. Gov. Can./Province of B.C., 40 p.

Four high-elevation sites in lower coastal B.C. were planted with 11 species, six "high-elevation" species and five "low-elevation" species. Survival, growth (total height, 10-yr leader length), stem diam, branch length, stem form (forks, basal sweep) and frost damage were recorded. Mountain hemlock was rated "acceptable" in height, 10-yr leader length, diameter and especially in forking. It ranked "poorer" to "low" in sweep, multiple leaders and stem breakage. Together with yellow cypress it was ranked as "questionable" for reliability, due to severe sweep and forking, and "poor" or "variable" for productivity. Natural regeneration is recommended for mountain hemlock. "Acceptable" planting species are amabilis fir, subalpine fir and Engelmann spruce. Noble fir is susceptible to frost damage. All low-elevation species were judged "always poor options."

162 SCHARPF, R.F.; PARMETER, J.R. (Technical coordinators) 1978. Proceedings of the symposium on dwarf mistletoe control through forest management, April 11-13, 1978, Berkeley, California. U.S. For. Serv., Gen. Tech. Rep. PSW-31, 190 p.

The symposium deals with the control of *Arceuthobium* spp. on conifers in western N. America. North America has 32 of the known 38 species of *Arceuthobium*, most of which occur in Mexico and the western United States. In Pacific Coast states, hemlock types (including mountain hemlock) are infested in about 21% of the area. *Arceuthobium tsugense* is the only species listed for these hosts. *Arceuthobium tsugense* is rare on mountain hemlock in British Columbia, although it is the principal host in California. Four (of the 30) papers, by Stewart, Bolsinger, Hadfield and Russell, and by Van Sickle and Smith, refer specifically to mountain hemlock.

163 SCHULLER, S.R. 1977. Vegetation ecology of selected mountain hemlock (*Tsuga mertensiana*) communities along the eastern high Cascades, Oregon. MSc Thesis, Oreg. State Univ., Corvallis. 79 p.

Fifty-one stands dominated by mountain hemlock were studied. Three vegetation subzones were identified, based on relative frequency of tree-size classes, relative density of seedlings and species composition. Mountain hemlock dominates and is reproducing in the Subalpine subzone; mountain hemlock dominates also in the Transition subzone, where Pacific silver fir development is suppressed by heavy snow; mountain hemlock dominates currently the Montane subzone, but Pacific silver fir is the probable climax species.

164 SCHULLER, S.R.; FRENKEL, R.E. 1981. Checklist of the vascular plants of the Steamboat Mountain Research Natural Area. U.S. For. Serv., Res. Note PNW-375, 20 p.

Brief descriptions are given of the 8 major habitats and their community types found in this area in the Gifford Pinchot National Forest, Washington. Forest types are *Abies lasiocarpa, A. amabilis/Tsuga mertensiana, A. amabilis/T. mertensiana/Picea engelmannii, A. amabilis* and *Pseudotsuga menziesii/A. procera/T. mertensiana.* Habitats and types within which each species occurs are indicated.

165 SEIDEL, K.W. 1979. Regeneration in mixed conifer clearcuts in the Cascade Range and Blue Mountains of eastern Oregon. U.S. For. Serv., Res. Pap. PNW-248, 24 p.

Clearcuts were adequately reforested with a mixture of advance, natural, and planted reproduction. At higher elevations in the Cascades, considerable amounts of true fir and mountain hemlock advance reproduction were present and this played a significant role in mountain hemlock clearcuts where slash is left untreated. Unconventional slash-disposal methods have been shown to minimize damage to such advanced reproduction. Mountain hemlock seedling establishment was better on more northerly aspects; increasing amounts of grass had a negative effect on stocking.

166 SEIDEL, K.W. 1983. Regeneration in mixed conifer and Douglas-fir shelterwood cuttings in the Cascade Range of Washington. U.S. For. Serv., Res. Pap. PNW-314, 17 p.

On average, shelterwood units in pure Douglas-fir stands contained 7111 seedlings or saplings/ac (2880/ha), while those in mixed stands (also containing *Abies grandis, Tsuga heterophylla, T. mertensiana* and *Larix occidentalis*) contained 1572/ac (636/ha). About 73% of the regeneration in the mixed stands and 96% in the Douglas-fir stands were of natural post-harvest origin. It is concluded that 6-8 Douglas-fir per ac (15-20/ha) and about 25 mixed conifers per ac (62/ha) should result in adequate stocking on most plots. Understocking in some of the mixed-conifer plots appeared to be related to non-uniform overstorey, lack of advance reproduction or high altitude.

167 SEIDEL, K.W. 1985. Growth response of suppressed true fir and mountain hemlock after release. U.S. For. Serv., Res. Pap. PNW-344, 22 p.

The growth response of supressed *Tsuga mertensiana* was measured after release in clearcuts, shelterwood areas, and uncut stands. Growth responses were found to be least in uncut stands and greatest in clearcuts. The best possible crop trees were determined by using stand variables and live crown-basal area ratios. Vigorous advance reproduction having live-crown ratios greater than 50% are the best candidates for crop trees.

168 SEIDEL, K.W.; COOLEY, R. 1974. Natural reproduction of grand fir and mountain hemlock after shelterwood cutting in central Oregon. U.S. For. Serv., Res. Note PNW-229, 10 p.

Mountain hemlock seedlings were found to be very sensitive to microclimatic extremes. Seedling survival was very low, even under high overstorey densities, and found to be dependent upon stand density as well. Seedling establishment and survival, soil and seedling moisture stress, and surface temperatures were examined and discussed. A single case study was used as the basis for this report and indicates that there is little research on stresses affecting mountain hemlock caused by logging pressure in the subalpine zone. Factors that could cause variation in natural regeneration in these sites are: seed supply, weather, seed-bed condition, and animal populations.

169 SETZER, T.S.; MEAD, B.R. 1988. Verification of aerial photo stand volume tables for southeast Alaska. U.S. For. Serv., Res. Pap. PNW-RP-396, 13 p.

Aerial photo stand-volume tables were developed using Forestry Inventory and Analysis data. Methods used to construct the tables are described. Tables were produced for three major conifer forest types: Sitka spruce (*Picea sitchensis*); spruce/hemlock, western hemlock (*Tsuga heterophylla*) and mountain hemlock (*T. mertensiana*) combined; and Alaska cedar (*Chamaecyparis nootkatensis*). A table was produced for all conifer types combined. Volume estimates compiled by two photointerpreters from aerial stand-volume tables were compared with ground-measured volume.

170 SHAW, C.G. III. 1982. Mountain hemlock is an occasional host for hemlock dwarf mistletoe in Alaska. Plant Dis. 66(9): 852-854.

Tsuga mertensiana is a rare host for *Arceuthobium tsugense* in Alaska and only one occurence of an infected stand was found in this state. In other states in the U.S., infection of *Tsuga mertensiana* is common, which leads to the hypothesis that different races of *Aceuthobium tsugense* exist.

171 SHOVEL, K.S.; ALVIN, K.L. 1987. Patterns of cuticular organization in the hybrid *Tsuga* X *jeffreyi* (Henry) Henry and its putative parents. Bot. J. Linn. Soc., Acad. Press, London. 94(3): 373-383.

Leaf-cuticle structure of *Tsuga mertensiana, Tsuga heterophylla* and *Tsuga* X *jeffreyi* were compared using light and scanning electron microscopy. Two components of the cuticle were analyzed; the waxy cuticular layer and the separate spongy layer beneath. The isolated cuticle from two proposed parental species was ascertained to have distinguishing characteristics. *Tsuga mertensiana* cuticle was discovered to be almost identical to that of *Tsuga* X *jeffreyi*, indicating that if *Tsuga* X *jeffreyi* is a hybrid, it has inherited its cuticular organization from *Tsuga mertensiana* only.

172 SINGER, M.J.; UGOLINI, F.C. 1976. Hydrophobicity in the soils of Findley Lake, Washington. For. Sci. 22: 54-58.

Studies in 1972 on sub-alpine soils from a 260-ha unmanaged catchment area of Washington, unburnt for >200 yr and supporting old-growth *Tsuga heterophylla, T. mertensiana* and *Abies amabilis*, showed that hydrophobicity of soil varied from non-hydrophobic to strongly hydrophobic. No hydrophobicity was found at low C content and a rapid increase at >5%. Hydrophobicity was correlated also with pyrophosphate-extractable C% and with the soil humic-acid/fluvic-acid ratio.

173 STANDISH, J.T.; MANNING, G.H.; DEMAERSCHALK, J.P. 1985. Development of biomass equations for British Columbia tree species. Can. For. Serv., Pac. For. Res. Cent., Info. Rep. BC-X-264. Victoria, B.C. 48 p.

Biomass equations, based on 1155 sample trees, were developed for 22 commercial species, including mountain hemlock, covering all of B.C. except the northern part of the Province and the Queen Charlotte Islands. Trees were destructively sampled and equations of the form $y = b_0 + b_1D^2H$ and multiple linear equations based on D, H and V and their interactions were developed. Both forms of equation give reasonably accurate and precise predictions; choice depends on the use to which the biomass equations will be put.

174 STOREY, B. 1974. A chromosome study of *Tsuga mertensiana*. Unpub. Rep., Biology 490, Dep. Biol., Univ. Victoria, B.C., 13 p. plus Appendix.

Root-tip squashes of germinants from one British Columbia seedlot were studied to determine chromosomal number and morphology. Diploid number (2n) of 24 was found. Squashes of pollen buds collected *in situ* near Vancouver confirmed the haploid number of 12. The longest chromosome was about 1.65 times as long as the shortest. Longer chromosomes were more metacentric than shorter ones. Only the shortest chromosome displayed a consistent constriction. An idiogram is presented.

175 SUGITA, S.; TSUKADA, M. 1982. The vegetation history in western North America. I. Mineral and Hall Lakes. Jpn. J. Ecol. 32: 499-515.

Pollen-analysis studies show a progressive succession of the vegetation in response to gradually changing climate in the Puget Lowland, Washington, over the last 19 000 yr. Eight pollen zones or subdivisions were recognized. Modern lowland coniferous forests, with a history of only 5000 yr, were extensively logged by euro-American settlers about 100 yr ago.

176 SUTHERLAND, J.R. 1979. The pathogenic fungus *Caloscypha fulgens* in stored conifer seeds in British Columbia and relation of its incidence to ground and squirrel-cache collected cones. Can. J. For. Res. 9: 129-132.

Stored seeds were assayed for the seed-borne fungus *C. fulgens* and the pathogen was not found in *Tsuga mertensiana* and *T. heterophylla* seedlots.

177 SUTHERLAND, J.R.; RING, F.M.; SEED, J.E. 1991. Canadian conifers as hosts of the pinewood nematode (*Bursaphelenchus xylophilus*): results of seedling inoculations. Scand. J. For. Res. 6: 209-216.

In two experiments, seedlings of 22 conifer species, including mountain hemlock, from across Canada were inoculated with *m* and *r* form isolates of the pinewood nematode (*Bursaphelenchus xylophilus*). Both nematode form isolates were equally pathogenic. Mountain hemlock was among the most resistant species.

178 SWAN, E.P.; NAYLOR, A.F.S. 1969. Alkaline ethanolysis of western conifer barks. Can. Dep. Fish. For., Bi-mon. Res. Notes, Ottawa 25: 32-33.

Earlier research on the alkaline ethanolysis of extractive-free *Thuja plicata* bark reported the yields and identification of several monomers from the bark suberin. Similar data are presented for other species including *T. mertensiana*. Cork cells in mountain hemlock are inferred by detection of suberin ethanolysis products. Percentage yields (7.7%) were similar to *T. heterophylla* (7.1%).

179 SWEDBERG, K.C. 1973. A transition coniferous forest in the Cascade Mountains of northern Oregon. Amer. Mid. Natur. 89: 1-25.

A 29-km transect was established in northern Oregon and the main coniferous forests, and an unusually rich flora (19 spp.), was examined. In discontinuous forests (1670-1770 m), mountain hemlock was the most important tree, diminishing in importance with lower elevations. Most vigorous reproduction occurred outside the closed canopy. In continuous forests (1500-1670 m), mountain hemlock was also the dominant species to about 1620 m; individual trees were smaller with decreasing elevation and litter accumulation was less. All through this transect, succession was still in progress with only the high-elevation mountain hemlock and the mid-elevation grand fir stands approaching climax.

180 SWEETEN, J.R. 1961. A study of ray tracheids in hemlock and balsam from southwestern British Columbia. Univ. B.C. For. Club, Res. Note 18: 5-6. Vancouver, B.C.

Because of their different strength properties, a method was sought of distinguishing hemlock (*Tsuga heterophylla* and *T. mertensiana*) from "balsam" fir (*Abies amabilis, A. grandis* and *A. lasiocarpa*), now sold indiscriminately as "hemlock" in the Vancouver district. Ray tracheids, found in all hemlock but only in one of the 200 "balsam" samples examined, provided a microscopic method of distinction, but no reliable macroscopic method of identification was found.

181 TARANKOV, V.I. 1973. [Some results of dendrochronological analysis of *Larix kurilensis* in the Kamchatka basin.] Pochvy i rastitel'n. merzlot. r-nov SSSR. 194-198. Magadan, USSR. (In Russian)

Cycles of 5-6, 7-11, 20-28 and 80-90 yr were observed in the radial increment of *L. kurilensis* (*L. gmelinii* var. *japonica*). Comparison of *L. kurilensis* with data for mountain hemlock (*Tsuga mertensiana*) in Alaska showed that the deep secular minima of increment were synchronous in the two species and these cycles closely resembled those of solar activity. It is suggested that the effect of the geomagnetic field on ring formation should be taken into account in dendroclimatological investigations.

182 TAYLOR, R.J. 1971. Phytochemical relationships in the genus *Tsuga*. Abstr. in Am. J. Bot. 58(5): 466.

A summary of the results of a phenolic pigment analysis of the genus *Tsuga* found chemical hybrids in the genus to be rare. Chemical similarities between *Tsuga* and *Picea* were discovered to be close, but no definite correlation could be made with the data found. Phylogenetic relationships between *Tsuga* species are explored.

183 TAYLOR, R.J. 1972. The relationship and origin of *Tsuga heterophylla* and *Tsuga mertensiana* based on phytochemical and morphological interpretations. Am. J. Bot. 59(2): 149-157.

Morphological intermediacy between *Tsuga heterophylla* and *Tsuga mertensiana* has stimulated controversy concerning the relationship between these two hemlock species and has led to wide acceptance of hybridization as a causative factor of intermediate forms in areas of distributional overlap. Comparative chemical analyses were used to test the theory of hybrid derivation of intermediates. Chromatographic analyses suggested that *Tsuga mertensiana* is a derivative of intergeneric hybridization involving *Tsuga heterophylla* and *Picea sitchensis*. It was concluded that hybridization of *Tsuga mertensiana* and *Tsuga heterophylla* is a possible but rare phenomenon and is not necessarily indicated by morphological intermediacy. Phylogenetically, both of these species are typical representatives of *Tsuga* and are distinct from species of *Picea*.

184 TAYLOR, R.J.; SHAW, D.C. 1983. Allelopathic effects of Engelmann spruce bark stilbenes and tannin-stilbene combinations on seed germination and seedling growth of selected conifers: *Picea engelmannii, Abies lasiocarpa, Tsuga mertensiana, Pinus contorta*. Can. J. Bot. 61 (1): 279-289.

Seed germination and other aspects of plant development in *Tsuga mertensiana* and *Pinus ponderosa* were found to be more tolerant of the inhibitory effects of *Picea engelmannii* bark extracts, composed mainly of hydroxy stilbenes and condensed tannins, than most of the other species. *T. mertensiana* was also very tolerant in the same soil conditions as *P. engelmannii*.

185 TAYLOR, R.L.; TAYLOR, S. 1980. *Tsuga mertensiana* in British Columbia. Davidsonia 11(4): 78-84.

Tsuga mertensiana is described briefly in terms of natural distribution and habitat, morphology and structure, biology (including sexual and vegetative reproduction), varieties and cultivars (such as *Tsuga X jeffreyi*), propagation, transplanting, cultivation, landscape value, availability, uses, ethnobotany, diseases and problems of cultivation, and name origin.

186 THORNBURGH, D.A. 1969. Dynamics of the true fir-hemlock forests of the west slope of the Washington Cascade range. Diss. Abstr. Int. 30: 2489B.

Discusses the factors controlling distribution patterns of tree species, including mountain hemlock, of climax communities and seral stages at various altitudes in true fir-hemlock forests. Similar distribution patterns were found in other areas in the Cascade mountains.

187 TOPIK, C. 1982. Forest floor accumulation and decomposition in the western Cascades of Oregon. Diss. Abstr. Int. 43: 1725B.

This study is a description of the soils along an elevational gradient from a sample of seven old-growth stands and an analysis of the factors that cause the change from mull to mor humus. The principal tree species are large *Pseudotsuga menziesii* and *Tsuga heterophylla* at low elevations, and smaller *Abies amabilis* and *Tsuga mertensiana* at high elevations. With elevation, forest floor mass increases linearly, litterfall rates decline, and soil-nutrient stocks (N, P, K, Ca, Mg) decrease logarithmically. Litterfall was maximal at 793 m (313 g/m^2/yr) and minimal at 1740 m (184 g/m^2/yr). Estimated forest-floor-turnover times ranged from 8.7 yr at 610 m to 44.0 yr at 1740 m. At high elevations, up to 43% of total soil N and 57% of total soil organic matter occur in the forest floor. Decomposition varies inversely and linearly with elevation. Elevation accounts for 72% of the variation in the L layer weight loss after one yr. High-elevation species decomposed less, regardless of elevation. A 1-yr factorial experiment with *P. menziesii* foliage showed that 47% of decomposition variability is due to climate and 30% to site-specific litter quality. Laboratory experiments (100-day incubations at 10°C) verify the site and species-specific differences in litter quality. Lignin, tannin and calcium contents (multiple regression) partly explain these differences in detritus decomposition rates. The results are compatible with the general hypothesis that recalcitrance of a species' foliage results from adaptation to a site's nutrient status and that tree-nutrient frugality and secondary-compound production accompany low site fertility.

188 VERMES, J.F.; MYROLD, D.D. 1992. Denitrification in forest soils of Oregon. Can. J. For. Res. 22(4): 504-512.

In soils from eight mature conifer stands including mountain hemlock (*T. mertensiana*), denitrification potentials were highly correlated with soil-NO_3^- concentrations and soil-water contents; these two soil variables explained more than 90% of the variation in denitrification potentials. Up to 79% of the variation in field denitrification rates was explained by soil-water content. Experiments confirmed the importance of soil-water content as a regulator of denitrification and suggested that active denitrification requires formation of anaerobic microsites. Extrapolation of seasonal denitrification measurements suggests that relatively little N (<10 kg N/ha) is lost annually from Oregon forest soils as N gases.

189 VIERECK, L.A.; DYRNESS, C.T. 1980. A preliminary classification system for vegetation of Alaska. U.S. For. Serv., Gen. Tech. Rep. PNW-106, 38 p.

A hierarchical system, with five levels of resolution, is proposed for identifying Alaskan vegetation. At the broadest level of resolution the system contains five formations - forest, tundra, shrubland, herbaceous vegetation, and aquatic vegetation. Mountain hemlock occurs in three associations: the subalpine fir type, which occurs in scattered locations near the treeline in southeastern Alaska; the mountain hemlock type, which occurs on saturated soils near timberline, and which covers considerable land area both on the mainland and on the major islands of southeastern Alaska, as well as a narrow sub-alpine band in south-central Alaska; and the western hemlock-mountain hemlock type in the southeastern part of the State, which is transitional between the subalpine mountain hemlock zone and the Sitka spruce-western hemlock zone.

190 VIERECK, L.A.; LITTLE, E.L. JR. 1972. Alaska trees and shrubs. U.S. Dep. Agric., Agric. Handb. 410. Washington, D.C. 265 p.

Describes and illustrates native woody plants, including mountain hemlock (pages 59-60). Most trees and shrubs can be identified by reference to drawings, descriptions and maps, but keys based mostly on vegetative characters are provided also.

191 VOGT, K.A.; DAHLGREN, R.; UGOLINI, F.; ZABOWSKI, D.; MOORE, E.E.; ZASOSKI, R. 1987. Aluminium, Fe, Ca, Mg, K, Mn, Cu, Zn and P in above-and below ground biomass. I. *Abies amabilis* and *Tsuga mertensiana*. Biogeochemistry 4: 277-294.

In a mature mixed subalpine stand of *Tsuga mertensiana* and *Abies amabilis*, significantly higher Al levels were found in foliage, branch and root tissues of *T. mertensiana*. Differences in concentration were found between species in current and older foliage, and fine roots. Similar trends were found in branches and foliage, phloem and xylem and roots >2 mm diam. The two species were different in accumulating specific elements from the soil.

192 VOGT, K.A.; GRIER, C.C.; MEIER, C.E.; EDMONDS, R.L. 1982. Mycorrhizal role in net primary production and nutrient cycling in *Abies amabilis* ecosystems in western Washington. Ecology 63: 370-380.

The potential contribution of mycorrhizal fungi (as sporocarps and mycorrhizal sheaths) to total ecosystem biomass and turnover and nutrient distribution and turnover was examined in a 23-yr-old and a 180-yr-old Pacific silver fir (*Abies amabilis*) stand that contained mountain hemlock. While mycorrhizal fungi contributed roughly 1% to total ecosystem biomass in both stands, the percentage of net primary production (NPP) in the mycorrhizal-fungal component was roughly 14% in the younger stand and 15% in the mature stand. Mycorrhizal fungi plus conifer fine roots contributed ≈45% of NPP in the young stand and ≈75% in the mature stand.

193 VOGT, K.; MOORE, E.; GOWER, S.; VOGT, D.; SPRUGEL, D.; GRIER, C. 1989. Productivity of upper slope forests in the Pacific Northwest. Pages 137-163 *in* D.A. Perry; R. Meurisse; B. Thomas; R. Miller; J. Boyle; J. Means; C.R. Perry and R.F. Powers (editors). Maintaining the Long-term Productivity of Pacific Northwest Forest Ecosystems. Timber Press, Portland, Oreg. 256 p.

Comprehensive review of location, climate, species composition, development, structure, productivity, longevity and management prospects of forests in the region. Mountain hemlock is considered to be above the amabilis fir zone, and occurs from 1250 m to 1700 m and above in areas where snowpacks can average 3 m and reach 6 m. Canopy is closed at lower elevations in the zone, but trees are clumped toward the upper limit. Regeneration may be slow due to limited seedbeds (rotting logs) and low soil temperatures. Height growth stops at about 250 yrs. Foliar persistence ranges from 5 to 19 yr and biomass is high. Slow decomposition may mean nutrient deficiencies leading to disease and insect attack and clumped failure, thus opening sites to regeneration. Limits on ground disturbance and slashburning are discussed.

194 WALSH, S.J. 1980. Coniferous tree species mapping using Landsat data. Remote Sensing of Environ. 9: 11-26.

The identification and mapping of 12 surface-cover types, including seven classes of coniferous tree species, was accomplished using LANDSAT digital data. Compared with detailed ground-truth records, mapping accuracy ranged from 84% (ponderosa pine/white fir type) to 95% (water). Mountain hemlock and shasta red fir (where either was the dominant species) types were mapped with 88-89% accuracy.

195 WALTERS, B.B. 1991. Small mammals in a subalpine old-growth forest and clearcuts. Northwest Sci. 65: 27-31.

This study examined the differences between small mammal populations in a subalpine old-growth(>1200 yrs) forest containing mountain hemlock, and adjacent burned and unburned clearcuts. The results suggest that the effects of clearcutting on small mammal abundance are similar in lowland and subalpine forests, and that edge effects are an important consideration for future research, particularly in old-growth forests because they are favoured habitats for small mammals.

196 WARING, R.H.; CROMACK, K., JR.; MATSON, P.A.; BOONE, R.D.; STAFFORD, S.G. 1987. Responses to pathogen-induced disturbance: decomposition, and nutrient availability and tree vigour. Forestry 60(2): 219-227.

The effects of natural disturbance caused by *Phellinus weirii* on 150-250-yr-old mountain hemlock in near-pure stands and subsequent regrowth were examined on a number of ecosystems in Oregon. Decomposition rates and nitrogen availability measured *in situ* increased in the zones of young regrowth, but dropped to values common for old growth as the forest aged and the canopy closed. Phosphorus and potassium accumulation on exchange resins showed trends opposite to nitrogen, and may have been associated with changes in biomass. Increased nitrogen concentrations and decreased lignin concentrations in fine roots in the zone of young regrowth suggested improved tree nutrition under conditions of higher N availability and lower leaf area index. Tree vigour, estimated as wood production per unit leaf area, also was significantly increased in the zones where young forests grew. Circumstantial evidence suggests that increases in nutrient availability and light following death of the mature forest improved photosynthesis, leading to increased resistance of young trees against infection by the pathogen.

197 WARING, R.H.; EMMINGHAM, W.H.; GHOLZ, H.L.; GRIER, C.C. 1978. Variation in maximum leaf area of coniferous forests in Oregon and its ecological significance. For. Sci. 24: 131-140.

Total leaf areas were estimated in 17 natural stands in the western central Cascade Mts. (average 18 m^2/m^2) and in 23 stands in the eastern Siskiyou Mts. (average 35 m^2/m^2), in sites with similar temperature and moisture conditions. The lowest values occurred in subalpine stands of *T. mertensiana* (5 m^2/m^2). Nutrient deficiencies may account for low leaf areas.

198 WARING, R.H.; SCHROEDER, P.E.; OREN, R. 1982. Application of the pipe model theory to predict canopy leaf area. Can. J. For. Res. 12: 556-560.

Data are presented for 10 Oregon coniferous species (including mountain hemlock) showing close correlations between leaf area at four sampling positions in the crown and sapwood area at the same position, and between sapwood area at bh and total leaf area. Mountain hemlock was found to have a much lower trend than its associates (*Abies amabilis, A. lasiocarpa, A. procera, Picea engelmannii* or *Tsuga heterophylla*). Lower values are associated with species adaptation to full exposure or dessicating environments. These data support the pipe model theory.

199 WEBBER, J.F.; HANSEN, E.M. 1990. Susceptibility of European and north-west American conifers to the North American vascular pathogen *Leptographium wageneri*. Eur. J. For. Pathol. 20: 6-7, 347-354.

Tests for susceptibility to the native pathogen, *L. wageneri*, that causes black stain root disease, were performed on 9 North American and European conifer species including *T. mertensiana*. Less susceptible species included *T. heterophylla* and *T. mertensiana* which, although occasionally infected, were never killed by the fungus. The potential threat posed to conifers by *L. wageneri*, should it ever be introduced into Europe, is evaluated.

200 WILL, G.M.; YOUNGER, C.T. 1979. Some foliage nutrient levels in tree and brush species growing on pumice soils in central Oregon. Northwest Sci. 53: 274-276.

Foliage was collected from 6 tree species (including *Tsuga mertensiana)* and 4 shrubs on five sites, and analysed for major and minor nutrients. There were marked differences in nutrient contents among species, but not among sites. Sulfur deficiencies were found in all the trees.

201 WILLIAMS, C.B., JR. 1968. Seasonal height growth of upper-slope conifers. U.S. For. Serv., Res. Pap. PNW-62, 7 p.

Observations on growth were made in 1963 and 1964 on nine tree species in two areas of the Cascade Range at moderate to high altitudes. Compared with pine and redcedar, *Abies* spp. and *Tsuga mertensiana* had relatively short growing seasons based on the average number of days from Jan. 1 to bud-burst, and to completion of 50, 90 and 100% of growth, the length of the growing season and the total amount of growth.

202 WILLIAMS, C.B., JR.; DYRNESS, C.T. 1967. Some characteristics of forest floors and soil under the true fir/hemlock stands in the Cascade range. U.S. For. Serv., Res. Pap. PNW-37, 19 p.

Reports an exploratory study on forest floor and mineral soil on 46 plots in Oregon and Washington. The dominant species were *Abies amabilis, A. procera, A. magnifica* var. *shastensis*, or *Tsuga mertensiana*, none of the stands being pure. Mean forest-floor depth was 1.8 in (4.5 cm), and mean weight was 56 754 lb/ac (10 444 kg/ha). In most cases, the nutrient content of the forest floor varied little between forest types . Determinations of nutrient in both forest soil and underlying mineral soil showed that usually less than 25% of the total available nutrient supply is contained in the forest-floor material.

203 WILSON, J.D. 1961. Holocellulose determinations of mountain hemlock (*Tsuga mertensiana*) bark. For. Prod. J. 11(6): 260-3.

In experiments with bark of *T. mertensiana* (chosen because it has no cork fraction) and Douglas-fir bast fibres, the difficulties inherent in obtaining lignin-free holocellulose from extractive-free conifer barks were largely overcome by extraction with 1% anhydrous ethanolic KOH followed by a chlorite-acetic acid treatment. The method was not satisfactory with Douglas-fir wood holocellulose.

204 WILSON, J.D. 1964. The isolation and the properties of the bark phenolic acids from mountain hemlock, *Tsuga mertensiana* (Bong.) Carr. Diss. Abstr. 24: 3090-1.

The phenolic acid from the extractive-free outer bark consisted of two markedly different fractions, based on colour, solubility, methoxyl content and infrared spectra. They were separated on the basis that one was soluble in anhydrous dioxane, while the other was not. The fractions were similar in electrophoretic features (migration and band width).

205 WOODWARD, A.; SILSBEE, D.G.; SCHREINER, E.G.; MEANS, J.E. 1994. Influence of climate on radial growth and cone production in subalpine fir (*Abies lasiocarpa*) and mountain hemlock (*Tsuga mertensiana*). Can. J. For. Res. 24: 1133-1143.

Thirty yr of cone-production records for subalpine fir and mountain hemlock in the Cascade Mountains of Washington and Oregon were compared with basal-area increment and weather records to determine relationships among weather, radial growth, and cone crop. Cone production for both species was associated with (i) a cool, wet summer two yr prior, (ii) a warm, dry fall and winter, a cool spring and warm dry summer one yr prior, and (iii) a cool, wet winter immediately prior. Conditions that were conducive to good radial growth were conducive to a large cone crop the following year; that is, when a large cone crop occurred, radial growth in the same year was poor. The size of subalpine fir cone crops was negatively related to large crops in the previous 2 yr, and positively related to radial growth in the previous 2 yr. Mountain hemlock cone crops were negatively related to a large cone crop in the previous year and positively related to July or August temperature in the previous year.

206 WYKOFF, W.R. 1990. A basal area increment model for individual conifers in the northern Rocky Mountains. For. Sci. 36(4): 1077-1104.

A basal-area increment model was developed for 11 coniferous species, including *Tsuga mertensiana*. This model represents the diverse ecological requirements of each species. A range of predictor variables was calculated, and parameters for the model are discussed. Suppressed trees in dense stands were excluded in the development of this model.

207 YAIRE, J. 1980. The role of understory vegetation in the nutrient cycle of forested ecosystems in the mountain hemlock biogeoclimactic zone, Canada. Ecology 61(6): 1498-1514.

Mechanisms of nutrient redistribution through understorey vegetation in mountain hemlock forests by plant species, nutrient contents, litterfall, and biomass are discussed. The biochemical role of the understorey and its effects on the quantity of available nutrients is described. Variables affecting results include precipitation and seasonal changes.

208 ZOBEL, D.B.; ANTOS, J.A. 1982. Adventitious rooting of eight conifers into a volcanic tephra deposit. Can. J. For. Res. 12: 717-719.

During the second growing season after the 1980 eruption of Mount St. Helens in Washington State, stems of several coniferous species, including mountain hemlock, partially buried by tephra, produced adventitious roots, the first known instance of adventitious rooting by these species. Adventitious rooting was not found in Douglas-fir.

209 ZOBEL, D.B.; ANTOS, J.A. 1992. Survival of plants buried for eight growing seasons by volcanic tephra. Ecology 73: 698-701.

Long-term survival of two mosses (*Dicranum, Rhizomnium*), a herbaceous plant (*Erythronium montanum*) and two shrubs (*Vaccinium* spp.) in a subalpine (*Abies amabilis, Tsuga heterophylla, T. mertensiana*) forest, is documented. Most species (shrubs, herbaceous and bryophytes) survived burial for three summers, but species numbers were reduced sharply after eight summers. It was shown that completely buried plants can contribute to the revegetation of a site via delayed shoot emergence.

Subject index