The Mountain Hemlock Zone of British Columbia

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Forest Sciences Department
University of British Columbia
3036-2424 Main Mall
Vancouver, BC,
V6T 1Z4, Cananda

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COVER PHOTO

The cover photograph illustrates tree Islands at the lower elevation limit of the MH parkland. The photographs presented in this report were taken by K. Klinka, R.B. Brett, R.N. Green, and J. Pojar.

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1 INTRODUCTION

This report describes both forested and non-forested ecosystems of the Mountain Hemlock (MH) zone of British Columbia (also referred to as the subalpine MH zone, coastal subalpine forest, or coastal mountain hemlock forest). It is one of 14 technical reports intended to provide a comprehensive account of the biogeoclimatic ecosystem classification (BEC) system as well as some management implications for each zone in the province. These zonal reports should fill the gap between the general description given in "Ecosystems of British Columbia" (Meidinger and Pojar 1991) and the information on site identification and interpretation given in regional field guides (e.g., Banner *et al*. 1993, Green and Klinka 1994). Readers interested in a detailed account of the philosophy, principles, and methods of the BEC system should consult Pojar *et al.* (1987) or Meidinger and Pojar (1991). Information on coastal subalpine ecosystems of Washington and Oregon can be obtained from Franklin and Dyrness (1988) and of southeastern Alaska from Viereck *et al.* (1992).

Our intent was not to exceed the detail given in the seminal study of Brooke *et al.* (1970); instead, we present the vegetation, zonal, and site classification developed from data gathered over the past 20 years by the Ecological Program Staff of the BC Forest Service throughout the whole range of the MH zone. In addition to the classification, we included a measure of plant similarity for the delineated units and information from recent published and unpublished studies on forest dynamics, soil nutrient availability, regeneration, productivity, and dendrochronology carried out in the MH zone. In spite of new data and information, we consider our understanding of coastal subalpine ecosystems to be incomplete, as there are still many questions for which there are only speculative answers.

In this report, we combined, analyzed, synthesized, and interpreted all available data on forested and non-forested coastal subalpine ecosystems that were obtained using standard sampling and data analysis. The resulting classification is thus an integration of several local classifications using the database consisting of the 734 samples collected to date. Following a brief description of the environmental setting of the MH zone we give a brief description of the methodology. The pivotal sections present the zonal, vegetation, and site classifications. Each of the three classifications features a synopsis, diagnostic tables and a description of the delineated units. The next sections summarize other reports and deal with vegetation-environment relationships and silvicultural implications.

We anticipate that this and subsequent reports will (i) provide an adequate and up-to-date account on ecosystem classification according to the BEC system and (ii) be used as tools for further ecosystem studies, ecosystem mapping, and implementation of ecosystem-specific management.

2 REGIONAL DESCRIPTION

2.1 LOCATION AND DISTRIBUTION

The MH zone includes all subalpine ecosystems in an elevational band above the Coastal Western Hemlock (CWH) zone and below the Alpine Tundra (AT) zone that occur along British Columbia's coast, including the Queen Charlotte Islands (Haida Gwaii) and Vancouver Island (Figure 2.1.1). The lower elevation limit of the MH zone, marked by the replacement of western hemlock (*Tsuga heterophylla*) by mountain hemlock (*Tsuga mertensiana*), occurs at the point where snowfall dramatically increases due to cooler temperatures (Orloci 1965; Brooke *et al.* 1970). At higher elevations within the MH zone, ever deeper snow and shorter growing seasons restrict trees to elevated microsites and cause a gradation from continuous forest cover to tree islands. At yet higher elevations, the severity of the climate precludes tree growth and tree islands are replaced by alpine ecosystems.

Figure 2.1.1. Extent of the Mountain Hemlock zone in British Columbia.

Compared to other zones, the MH zone has an intermediate area and disjunct distribution as it is restricted to two coastal mountain systems: (1) the Coast Mountains (including the northernmost Cascade Mountains) and (2) the St. Elias - Insular Mountains. The zone spans the full length of the province, and similar ecosystems extend southward into the Cascade and Olympic Mountains of northern Washington (Franklin and Dyrness 1988) and northwestward into Alaska. The largest part of the zone is within the Coast Mountains, a range that extends from 49° to 62°N latitude and varies in width from 100 to 200 km. The barrier effect of intervening mountain ranges diminishes the maritime influence and restricts the zone to areas within approximately 150 km of the coast. Consequently, three distinct climatic variations of subalpine boreal climate are recognized: (i) **hypermaritime** (on the outer coast where storms first reach land); (ii) **maritime** (mostly on the windward slopes of the Coast Mountains); and (iii) **submaritime** (on the leeward slopes of the Coast Mountains within the coast-interior transition (Klinka *et al.* 1989)).

The lower and upper elevation limits of the MH zone decrease from south to north and from east to west. In southern BC, the main elevational range of the zone is approximately from 900 to 1600 m, while the corresponding range in northern BC is approximately from 300 to 900 m (Brooke *et al.* 1970). In southern BC, the lower limit descends to 800 m in hypermaritime locations, but is above 1200 m on the leeward slopes of the Coast Mountains.

2.2 CLIMATE

Proximity to the Pacific Ocean and rugged topography result in a cool, wet climate with deep and late-melting snowpacks. Frequent storms moving onshore, especially in the winter, are forced to rise by the mountain barrier which results in the heaviest precipitation in the province (Brooke *et al.* 1970; Table 2.2.1, also see Table 3.2.2). Snowpacks increase abruptly above the CWH-MH transition, and this point coincides with the freezing isotherm during winter (Peterson 1969; Brooke *et al.* 1970). The Coast Mountains maintain the maritime influence year-round by preventing the westward movement of continental air masses. As a result, near the coast the winters are warmer and wetter, and the summers cooler and wetter than at similar elevations in the interior.

Table 2.2.1. Sample climate data from climate stations in the MH zone.

Weather Station	Subzone	Elevation (m)	Mean Annual Precipitation (mm)[1]	Mean Snowfall (cm)	Mean Annual Temperature (°C)[2]
Hollyburn Ridge	mm	951	2954 (107, 435)	820	5.0 (-2.3, +13.2)
Grouse Mtn	mm	1128	2565 (100, 375)	817	4.6 (-2.2, +13.1)
Kildala Pass	mmp	1609	2793 (164, 428)	1816	-1.4 (-8.5, +6.9)
Premier	msp	418	2041 (52, 206)	1441	4.0 (-10.1, +14.7)

1   First number in parentheses = mean precipitation of driest month (mm); second number = mean precipitation of wettest month (mm).

2   First number in parentheses = mean temperature of coldest month (°C); second number = mean temperature of warmest month (°C).

The small number of climatic stations, especially at higher elevations and in more remote locations, means that an understanding of the climate must be extrapolated from the few available stations and the work of Brooke *et al.* (1970) (see Table 3.2.2). Mean annual temperature in the MH zone ranges from 0 to 5°C and the mean annual precipitation ranges from 1700 to 5000 mm, with 20 to 70% of this falling as snow (Brooke *et al.* 1970; Pojar *et al.* 1991). Maximum snow depth (2 to > 3 m) usually occurs in April (BC Min. Env. 1985) and late snowmelt results in a short growing season of 95 to 145 days in southern BC (Brooke *et al.* 1970; Burns and Honkala 1990). While winters are long, temperatures are seldom very cold and the insulation provided by snow usually prevents the ground from freezing. Frequent cloud cover throughout the year further moderates temperatures. These conditions, combined with the high moisture-holding potential of thick humus layers, mean that moisture deficits are only short-term and occur only on the most exposed ridge tops.

The majority of winter storms occur when temperatures are near the freezing point, resulting in very wet snow. The depth and density of the snowpack, which is usually 40 to 50% water by weight (BC Min. Env. 1985), damages trees and shortens the growing season by delaying snowmelt. Trees as tall as 5 m are commonly bent double by the weight of the snow and frozen under the snowpack until late spring.

The wet, very snowy, and moderate climate is unusual in the world and is outside the general classifications of Köppen, Trewartha, and Whittaker (Trewartha 1968; Brooke *et al.* 1970; Whittaker 1975). Klinka *et al.* (2000) classified the climate as maritime subalpine boreal, a class that reflects: (1) an excess of precipitation over evapotranspiration; (2) a mean temperature for the warmest month that is >10°C but <22°C; (3) fewer than 4 months with a mean temperature >10°C, and (4) index of continentality <20 (see Table 3.2.2).

2.3 PHYSIOGRAPHY AND SURFICIAL MATERIALS

The MH zone occupies the two westernmost belts of the Canadian Cordillera (Yorath and Nasmith 1995). The Coast Belt includes the Coast and Cascade Mountains on the mainland coast, while the Insular Belt includes the St. Elias Mountains of northern BC and the Insular Mountains on Vancouver Island and the Queen Charlotte Islands. The two belts are separated by the primarily ocean-covered Coastal Trough which includes the Hecate Depression (between the Queen Charlotte Islands and the mainland) and the Georgia Depression (between Vancouver Island and the mainland).

Granitic rocks, particularly quartz diorite and granodiorite (Holland 1976; Monger and Journeay 1994) dominate in the MH zone, comprising one of the largest plutonic complexes in the world (Monger and Journeay 1994). The physical properties of these rocks, especially their resistance to weathering, coarse texture and acidic to intermediate minerology, have strongly affected the zone's topography, soil development and resulting vegetation (Brooke *et al.* 1970; Ryder 1986). Other geologic processes that are locally important, especially between Whistler and Toba Inlet and in the Kitimat area, include volcanism, some sedimentation and metamorphism, which created mainly gneisses and schists. Volcanic features are most prominent from Mt. Garibaldi north through Mt. Meagher.

The mountains on Vancouver Island are mainly comprised of folded and faulted volcanic and sedimentary rocks which have been intruded by the granitic batholiths that form most of the highest peaks (Holland 1976; Yorath and Nasmith 1995). Non-granitic rocks include greywackes, argillites, limestones, and cherts, as well as rocks of volcanic origin (Holland 1976). The Queen Charlotte Mountains have a similar composition. The heavily glaciated St. Elias Mountains include some of North America's tallest peaks, and include both granitic and metasedimentary rocks (Ryder 1986).

Overlaid onto the geological foundation is the effect of numerous Pleistocene glaciations. The most recent Fraser glaciation reached its maximum extent only 15,000 years ago and retreated to near its current position about 10,000 years ago (Holland 1976; Yorath and Nasmith 1995). The westward flow of Pleistocene ice widened and deepened the valleys that today are the steep-sided fjords into which the major coastal rivers drain. From south to north, these rivers include the Squamish, Homathko, Klinaklini, Bella Coola, Dean, Skeena, Nass, Stikine, Taku, and Alsek (Holland 1976; Ryder 1986). Relatively flat-topped mountains are the result of ice sheets that covered many peaks. Higher peaks emerged as nunataks from the ice and now display the characteristic cirques and steep sides that result from alpine glaciation (Holland 1976; Ryder 1986). The steepening of valley sides and flattening of mountaintops by glaciation is of particular importance in the MH zone because the transition from montane to subalpine forests often coincides with the change from steep to subdued slopes at higher elevations.

A veneer of glacial deposits (drift) from the Fraser glaciation is the dominant soil parent material within the MH zone, especially on valley slopes and the subdued terrain once covered by ice (Holland 1976; Ryder 1986), except on mountain peaks and ridges where unconsolidated materials were scraped off and transported away (Brooke *et al.* 1970; Yorath and Nasmith 1995). The drift is mainly till, with a relatively minor component of fluvial and lacustrine materials, that has been overlaid by colluvial and organic materials.

Alpine glaciation is still very active above and even within the MH zone, especially in the Coast and St. Elias Mountains. Since the retreat of Fraser ice, mountain glaciers have fluctuated with minor climatic changes, such as the recent Little Ice Age that caused the greatest glacial advance since the Pleistocene (Brooke *et al.* 1970; Ryder 1986). Such fluctuations directly impact the MH zone's upper limit. For example, warming in the past century has resulted in earlier snowmelt and the establishment of trees above the former timberline (Brink 1959; Brooke *et al.* 1970; Franklin *et al.* 1971). The zone is similarly sensitive to climate change at its lower limit where even slight warming would significantly reduce the snowpack (Burns and Honkala 1990).

2.4 SOILS AND HUMUS FORMS

Soil development has been strongly affected by Pleistocene glaciation, particularly the very recent retreat of ice and its deposition of glacial drift. Soils are therefore young, but are still well developed (Brooke *et al.* 1970). Except on the most rapidly drained ridges, soils are moist to saturated throughout the year (Brooke *et al.* 1970) and the mean annual soil temperature ranges form 2 to 8°C (Lavkulich and Valentine 1986). The cool and moist climate slows decomposition and large accumulations of organic materials result (Pojar *et al.* 1991). The dominant processes are podzolization, gleization, and Mor humus formation (Krajina 1969; Brooke *et al.* 1970; Pojar *et al.* 1991).

The abundance of granitic parent materials results in soils that are mostly coarse- to medium-textured (Ryder 1986). The most common soils are Humic and Ferro-Humic Podzols (Agriculture Canada Expert Committee on Soil Survey 1987), though Folisols may also develop on forested sites underlain by bedrock (Brooke *et al.* 1970). Subdued terrain, especially at the upper elevation limit of the zone, usually features fens and bogs with poorly drained organic soils (Fibrisols, Mesisols, Humisols). Recent deglaciation in the parkland subzone, as well as solifluction and the development of graminoid communities, have increased the importance of Regosols and Brunisols. Decomposition of organic matter in forested communities is primarily mediated by fungi. As a result, thick, acidic, snow-compacted Mor humus forms, including Hemimors, Humimors (Figure 2.4.1), Resimors, and Lignomors, are prevalent (Pojar *et al.* 1991; Green *et al.* 1993).

Figure 2.4.1. Note the cracked portion just above the mineral soil. This is a very old (ancient) portion of the H horizon.

2.5 VEGETATION

Forested ecosystems represent a complex of plant communities that varies with soil moisture, soil nutrients, and local climate (elevation, slope position, and slope aspect). Microtopography is a strong determinant of vegetation patterns at the upper elevation limit of the MH zone. Here trees are mostly restricted to clumps termed tree islands (where snowmelt is earliest), while the surrounding areas are occupied by non-forested ecosystems, mainly heaths and meadows. In spite of this complex pattern, there are strong floristic similarities between forested and non-forested communities, especially the dominance of two plant families: Pinaceae among trees, and Ericaceae among shrubs. Bryophytes (mosses and liverworts) are more prevalent in the forested ecosystems, while herbs and graminoids are more prevalent in non-forested ecosystems.

The three main tree species within the forested ecosystems are mountain hemlock, Pacific silver fir (*Abies amabilis*) and Alaska yellow-cedar (*Chamaecyparis nootkatensis*). Krajina (1969) proposed that susceptibility to damage from freezing is responsible for their near-absence from the colder Engelmann Spruce - Subalpine Fir (ESSF) zone, where the ground commonly freezes before significant snowfall. These species are well-adapted to the late seral environment because they can regenerate in low light, tolerate heavy snow loads and short growing seasons, and are long-lived (Burns and Honkala 1990; Brett 1997; Klinka *et al.* 2000). Recorded maximum ages include >775 years for Pacific silver fir (Brett 1997), 1824 years for Alaska yellow-cedar, and >1000 years for mountain hemlock (Pojar and MacKinnon 1994). On sites where these tree species are exposure-tolerant, they also adapt quickly to full light conditions after canopy disturbances (Herring and Etheridge 1976; Klinka *et al.* 1992; Brett 1997). These attributes allow the three species to be present in all stages of stand development.

Mountain hemlock is best adapted to the shorter growing season of the parkland subzone and it often forms the upper timberline. Pacific silver fir is the most frost- and drought-sensitive of the three species (Klinka *et al.* 2000) and is mostly absent at the highest elevations, while Alaska yellow-cedar is common there only in a krummholz (stunted) growth form. The increased continentality of higher elevation sites within the parkland subzone also allows an increased or even dominant role for subalpine fir, especially on the leeward slopes of Vancouver Island and the Coast Mountains, and in the Cascade Mountains.

Other tree species play minor roles within the zone, especially at the CWH-MH transition. Species occurring at the transition include western hemlock, western redcedar (*Thuja plicata*), and Douglas-fir (*Pseudotsuga menziesii*). Sitka spruce (*Picea sitchensis*) becomes an important species on the western slopes of the Queen Charlotte Islands and in northwestern BC (Pojar and MacKinnon 1994). Western white pine (*Pinus monticola*), though now seldom found as a canopy tree due to a blister rust, is restricted mostly to wet sites. The presence of subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*) increases where the maritime influence decreases, representing a transition between the MH and ESSF zones at high elevations. Drier sites in the parkland subzone sometimes support small populations of whitebark pine (*Pinus albicaulis*).

Ericaceous shrubs, particularly blueberries and huckleberries (*Vaccinium spp.*), are dominant in the acidic and poor soils that are pervasive in the MH zone. Alaska blueberry (*V. alaskaense*) is the most abundant species within the forested subzone; oval-leaved blueberry (*V. ovalifolium*) occupies similar habitats; black huckleberry (*V. membranaceum*) increases in importance at higher elevations and towards the coast-interior transition and is indicative of a more continental climate. Other ericaceous shrubs that are abundant in the forested subzone include false azalea (*Menziesia ferruginea*), white rhododendron (*Rhododendron albiflorum*) at higher elevations and on more continental sites, and copperbush (*Cladothamnus pyroliflorus*) on more maritime sites.

Low-lying ericaceous shrubs dominate in the parkland subzone, notably pink mountain-heather (*Phyllodoce empetriformis*; *P. glanduliflora* on the Queen Charlotte Islands), crowberry (*Empetrum nigrum*), joined by *Cassiope stelleriana* (= *Harrimanella stelleriana*) in northwestern BC, and white mountain-heather (*Cassiope mertensiana; C. lycopodioides* on the Queen Charlotte Islands). In southwestern BC, where raised microtopography allows the formation of tree islands, Cascade huckleberry (*V. deliciosum*) often forms an outer ring, and white rhododendron an inner ring between heath and tree island.

Bryophytes can form an almost continuous carpet on the forest floor. The most common species, pipecleaner moss (*Rhytidiopsis robusta*), is often accompanied by *Dicranum* spp., red-stemmed feathermoss (*Pleurozium schreberi*), lanky moss (*Rhytiadelphus loreus*), and fan moss (*Rhizomnium glabrescens*). On benches where the water table is high, peat mosses (*Sphagnum* spp.) can dominate. Bowls with late snowmelt in the parkland subzone support *Marsupella brevissima*.

Herbs on poor sites under the forest canopy include five-leaved bramble (*Rubus pedatus*), queen's cup (*Clintonia uniflora*), one-sided wintergreen (*Orthilia secunda*), and small twistedstalk (*Steptopus streptopoides*). One-leaved foamflower (*Tiarella unifoliata*) appears on medium sites and rich seepage sites support such herbs as clasping twistedstalk (*Streptopus amplexifolius*), skunk cabbage (*Lysichiton americanum*), and Indian hellebore (*Veratrum viride*).

The lush subalpine meadows that are characteristic of the parkland subzone rely on abundant growing season moisture from late-melting snowfields. Stream-edge communities include monkey-flower (*Mimulus* spp.), broad-leaved willowherb (*Epilobium latifolium*), yellow willowherb (*E. luteum*), and sweet coltsfoot (*Petasites frigidus*). Where seepage is the main source of moisture and nutrients, frequent herbs include Sitka valerian (*Valeriana sitchensis*), subalpine daisy (*Erigeron perigrinus*), mountain arnica (*Arnica latifolia*), leatherleaf saxifrage (*Leptarrhena pyrolifolia*), and mountain sorrel (*Oxyria digyna*).

Within the forested subzone, graminoids are restricted mostly to non-forested peatlands on benches. These fens and bogs support narrow-leaved cottongrass (*Eriophorum angustifolium*), tufted clubrush (*Trichophorum cespitosum*), tufted hairgrass (*Deschampsia cespitosa*), and rushes (*Juncus* spp.). Within the parkland subzone, late snowmelt bowls are occupied mostly by black alpine sedge (*Carex nigricans*). The other main sedges in the parkland subzone are showy sedge (*C. spectabilis*) which grows on seepage sites and near stream edges where nutrient levels are high, and small-leaved sedge (*C. macrochaeta*).

Ferns are more common in the forested subzone than in the parkland subzone. Deer fern (*Blechnum spicant*) is characteristic of poor sites, while medium sites support spiny wood fern (*Dryopteris expansa*) and rich seepage sites support oak fern (*Gymnocarpium dryopteris*) and lady fern (*Athyrium filix-femina*). A common fern-ally is running clubmoss (*Lycopodium clavatum*). Parsley fern (*Crytogramma crispa*) and fragile fern (*Cystopteris fragilis*) are found mostly on rocky sites in the parkland subzone, especially on talus slopes.

Epiphytic lichens are abundant in old-growth forests and include witch's hair (*Alectoria sarmentosa* and *A. vancouverensis*) and horsehair lichens (*Bryoria* spp.). Terrestrial lichens, notably *Cladina* spp., increase in importance in the parkland subzone, especially where a bouldery heath is present.

Cutover sites in the forested subzone are commonly dominated by blueberry shrubs and advance regeneration of Pacific silver fir (Green and Bernardy 1991; Brett 1997). Sites where tree regeneration is less reliable, especially where slashburning has killed advance regeneration, are likely to be dominated by fireweed (*Epilobium angustifolium*), bunchberry (*Cornus canadensis*), juniper haircap moss (*Polytrichum juniperinum*), and twinflower (*Linnaea borealis*).

2.6 WILDLIFE

Few, if any, animal species are limited to the MH zone; nonetheless, it provides habitat for many species that move through it at different times of the year. Most of these species move up into the zone as low-elevation vegetation is depleted. For example, bears and many birds move to the MH zone in late summer to feed on ripe berries. Meidinger and Pojar (1991) summarized the specialized habitat requirements of many species. Mountain goats inhabit alpine or subalpine open areas during the summer months but require forested habitat during the winter months. Most large mammals, such as black and grizzly bears, blacktailed deer, and Roosevelt elk, mainly use meadows, south-facing rock outcrops and avalanche tracks, but also forested areas. Pikas are restricted to talus slopes and Vancouver Island marmot habitat is only found in parkland or herb meadows on Vancouver Island. Wildlife species in the MH zone often require specialized habitat such as old-growth forests (cougar, snowshoe hare, southern red-backed vole, Columbian mouse and Douglas squirrel) or wetlands (water vole, Pacific giant salamander, and tailed frog).

Birds that eat bark, wood boring insects, conifer seeds or other birds and small mammals, such as the great horned owl, great grey owl, Clark's nutcracker, raven, common flicker, pileated woodpecker, chestnut-backed chickadee, red-breasted nuthatch, Townshend's warbler, and golden crowned kinglet inhabit old-growth forests. Golden eagles, white-tailed ptarmigan and willow ptarmigan are found in subalpine meadows and forest openings. Blue grouse breed in lower elevation habitats, but move upwards into the subalpine forests to spend the winter.

2.7 LAND USE

Inaccessibility and the short growing season have restricted the zone's use for commercial activities and timber extraction reached the MH zone only in the 1960's. The timber production potential in the zone is limited by low productivity, especially at higher elevations, and there are concerns that timber extraction, particularly using low-elevation methods, is inappropriate at higher elevations (Pojar *et al.* 1991; Brett 1997). There is no significant settlement, agriculture, or grazing, but the extraction of pine mushrooms has recently become economically significant on the zone's easternmost fringes. Mining and hydroelectric power developments were the first commercial uses of the MH zone. The steep valleys and high precipitation have been used for the generation of hydroelectric power, most notably the Kemano aluminum smelter power project where the eastward-flowing Nechako River was dammed and diverted to flow westward through the Coast Mountains.

An increasing proportion of the MH zone is protected by Provincial Parks (*e.g.* Garibaldi, Khutzymateen, Tetrahedron and Strathcona Provincial Parks). Recreation both within and outside of parks has dramatically increased with the increases in BC's population and tourism from outside BC. Skiing is the main commercial recreational use of the zone, while non-commercial activities include hiking, mountain biking, and hunting.

Though not measured economically, fresh water is a precious commodity. Perhaps the greatest value of the MH zone is as a watershed. The relatively open forest canopy is ideal for capturing and retaining snow (Brooke *et al.* 1970; Brett 1997): this prevents spring flooding and provides clean water even during dry summers.

3 ECOSYSTEM CLASSIFICATION

3.1 CONCEPTS AND METHODS

Concepts of Ecosystem Classification

The concept of an ecosystem must be defined before ecosystems are classified because different concepts would lead to different classifications. We define a terrestrial ecosystem (local ecosystem or biogeocoenose) as a landscape segment that is relatively uniform in five basic components: climate, soil, plants, animals, and microorganisms (Klinka and Krajina 1986; Pojar *et al.* 1987). Climate and soils represent the site (environment or habitat), and vegetation, animals, and microorganisms represent the biotic community of the ecosystem. Vegetation and soils are the most easily studied ecosystem components; hence, for convenience, each individual ecosystem is represented by a polypedon occupied by a particular plant community. Both vegetation and soil develop as result of the integrated effect of climate, topography, soil parent material, organisms, and time (Jenny 1941; Major 1951).

In taxonomic classification individual ecosystems are grouped into classes and the classes are grouped into a hierarchy based on the similarity in selected properties. The purpose of any taxonomic classification is to organize the objects in a way that will bring to mind many characteristics of each unit (taxon) and the greatest number of relationships with other units (taxa) (Cline 1949). Thus ecosystem classification provides a tool (system) for recognizing similar and different ecosystems. As similar ecosystems are expected to respond in a similar way to the same manipulation or treatment, the classification also provides a framework for the application of ecosystem-specific management.

Both climate and soil are expressions of the combined effect of many individual environmental factors each directly or indirectly affecting plants. Vascular plants are always dependent on climate, (light and heat), soil moisture, soil nutrients, and soil aeration; therefore we chose these factors to characterize site quality. Sites with the same or an equivalent combination of climatic, soil moisture, soil nutrient, and soil aeration conditions, *i.e.*, ecologically-equivalent sites, have the same or very similar site quality, and hence, the same or similar potential to support a certain vegetation.

The zonal or climatic climax concept predicates that there are ecosystems in which the integrated influence of the regional climate on the vegetation and the soil is most strongly expressed relative to other ecosystems. Such ecosystems have been termed zonal. With respect to solar radiation, light, temperature, soil moisture, and soil nutrient conditions zonal ecosystems are intermediate between the extremes found within an area with a specific regional climate. Under these conditions, ecosystem processes will be least influenced by local topography and soil parent materials, and the climax vegetation will reflect the influence of the regional climate more strongly than in azonal ecosystems.

To show relationships among ecosystems in form, space, and time, the BEC system organizes ecosystems at the local, regional, and chronological levels of integration. At the local level, (local) ecosystems are organized into a hierarchy of classes according to similarities in vegetation composition and structure or site quality. This organization is done by vegetation or site classification which frames vegetation or site units, respectively. At the regional level, regional ecosystems (*i.e.*, a group of geographically adjacent local ecosystems within a uniform climatic space) are organized into a hierarchy of classes according to similarities in the distribution of zonal ecosystems. This organization is done by a zonal (climatic) classification which frames zonal (biogeoclimatic) units. At the chronological level, local ecosystems are organized into site-specific chronosequences according to similarities in vegetation developing on a site of a given ecological quality. This organization is done by arranging the vegetation units delineated for a given site unit according to the type of disturbance or manipulation and the developmental stage. Due to the lack of data on disturbed ecosystems in the MH zone, this report does not describe site-specific chronosequences.

Ecosystem Sampling

The data used for classification included 734 sample plots (relevés) that were located subjectively in natural ecosystems without a recent history of human-caused disturbance. We used unpublished survey records on file with the Ecology Program Staff in Smithers and Vancouver, BC, and the data of Archer (1963), Brooke *et al.* (1970), Beese (1981), and Lewis (1982, 1985). The data were collected using the same or very similar sampling methods as outlined in Brooke *et al.* (1970) and Luttmerding *et al.* (1990). Each sample plot (usually a 0.04 ha square or rectangle) was chosen in a portion of the selected ecosystem judged to be relatively uniform in floristic composition, stand structure, and site attributes (slope position, aspect and gradient; soil depth, texture, parent materials and coarse fragment content, and thickness and sequence of soil horizons).

All plant species present within the sample plot were identified and their cover was estimated using the ten-class (+ to 9) Domin-Krajina scale of species significance (Mueller-Dombois and Ellenberg 1974) or direct estimates of percent cover. Nomenclature followed Little (1979) for trees, Taylor and MacBryde (1977) for other vascular plants; Ireland *et al.* (1987) and Stotler and Crandall-Stotler (1977) for bryophytes; and Hale and Culberson (1970) for lichens. The type and cover of ground surface materials (forest floor, decaying wood, mineral soil, coarse fragments, bedrock, and open water) was recorded. Soil moisture and nutrient regimes were estimated in the field by a systematically guided evaluation of a selected number of topographic (slope aspect, gradient, and position) and soil morphological properties (humus form, rooting depth, soil texture, coarse fragment content, soil aeration, soil mineralogy, and the presence and depth of the growing-season water table). This procedure is based on interpreting relationships between these properties, soil water-holding capacity, and available nutrient levels in the soil (Green and Klinka 1994). A more complete description of the field methods is given in Brooke *et al.* (1970), Luttmerding *et al.* (1990), and Green and Klinka (1994).

One or more soil pits were dug in each sample plot to obtain information about soil and its variation associated with a particular plant community. The pits were dug either to unweathered parent material or to an impermeable layer, and in all cases their depth met the standards for the control section. Description and sampling of pedons followed the practices and terminology of the Agriculture Canada Expert Committee on Soil Survey (1987). The following attributes were described for individual soil horizons: thickness, boundary, moist colour, mottles, texture, coarse fragment content and type, and root distribution. Other pertinent features observed during the description were also recorded. Humus form description and identification followed the procedure and classification system given in Green *et al.* (1993).

The classification in this report was done in the following sequence: (1) vegetation classification, using all sample plots; (2) zonal classification, *i.e.*, vegetation classification using only samples of zonal ecosystems, (3) site classification, using the results of vegetation and zonal classifications and environmental data.

Vegetation Classification

Our objective was to produce ecologically meaningful classes of ecosystems that could be identified and used as a framework for examining vegetation-environment relationships. Consistent with the methods of the biogeoclimatic ecosystem classification, the plots within each group had to represent communities that had affinities in floristic composition and physiognomy, and the groups of plots were required to (1) be floristically distinct, (2) occupy a floristically defined segment of edaphic and local climatic gradients. The classification was done separately for forested and non-forested ecosystems.

We classified the ecosystems into vegetation units at five categorical levels (in order of increasing generalization they are: subassociation, association, alliance, suborder, and order) using the Braun-Blanquet approach (Mueller-Dombois and Ellenberg 1974: 177-210; Westhoff and van der Maarel 1980: 287-399). This method consists of grouping the plots in a way that each group is separated from all other groups by an exclusive diagnostic combination of species. These diagnostic species must be either **differential species**, which have a much higher presence (proportion of plots of a group that it occurs in) than in other groups, or **dominant differential species**, which have higher species significance (percent cover) than in other groups. The exact criteria are as follows (Becking 1957):

differential species: species that may be associated with more than one vegetation unit in a hierarchy; presence class ≥ III (occurring in ≥ 40% of the plots of this unit) and at least two presence classes greater than in other units of the same hierarchical level within the same higher level unit.

dominant-differential species: species that may be associated with more than one vegetation unit in a hierarchy; presence class ≥ III, mean species significance ≥ 5 (≥ 10% cover) and two or more species significance classes greater than in other units of the same hierarchical level within the same higher level unit.

There is no universally accepted methodology for, nor agreement upon, the required composition of the diagnostic combination of species for a particular category (Becking 1957; Mueller-Dombois and Ellenberg 1974; Westhoff and van der Maarel 1980). We used the principle of relative differentiation that allows delineation of a subassociation or association by an exclusive diagnostic combination of species that must include at least one differential species or dominant-differential species. However, a subassociation or association that represents the central concept, *i.e.* typic, of a higher circumscribing unit can be recognized without a diagnostic combination of species because it is differentiated by the absence or low occurrence of species that characterize other subassociations or associations of the same hierarchical level within the same higher level unit (Pojar *et al.* 1987: 131-132).

The major tool used to achieve this objective was a computer-aided program, VTAB-Ecosystem Reporter, Revision 19907a (Emanuel 1999), which produces the various tables required in the analysis and synthesis of vegetation data. It arranges columns (plots or groups of plots) and rows (species) according to the criteria specified by the user for each step of the tabular analysis and synthesis.

The following four analytical steps were used to synthesize the data:

Step 1 Plots were stratified into floristically similar groups using a two-way indicator species analysis (TWINSPAN, Hill 1979). This program divides the plots into two groups, then further subdivides each of these groups in subsequent steps. When all the plots in a group are relatively uniform according to predetermined criteria, subdivision of this group stops.

Step 2 For each of the groups obtained in step 1, a tentative vegetation plot table, which shows the species significance of each species in all plots of the group was produced and examined for within-group similarities and differences. A tentative differentiated summary vegetation table, showing species presence and average species significance for each group, was used to examine floristic affinities and differences between groups.

Step 3 Tentative environmental plot tables, which show selected environmental characteristics for all plots within each group were used to determine whether the floristically similar plots were also similar in environmental characteristics. Floristically and environmentally aberrant plots were reassigned to the group to which they were most closely related. After reassignment, the summary vegetation tables were inspected to determine to which extent the groups of plots could be differentiated from each other in a hierarchical manner. The groups that could not be differentiated were merged.

Steps 2 and 3 were repeated iteratively in a process of successive approximation (Poore 1962), in which the production of revised vegetation and environmental tables continued until there were no plot reassignments and group mergers.

Step 4 A tentative hierarchy of groups was then proposed, where each group was considered to be either an association or a subassociation depending on its relationship to the hierarchy. A preliminary diagnostic table showing the diagnostic combination of species for every group was produced.

Step 4 was repeated in a process of successive approximations in which the production of tentative diagnostic tables continued until exclusive diagnostic combinations of species were obtained for each group of the

hierarchy. This process typically required changes in the structure of the hierarchy, and, occasionally, merging of some of the groups lacking a diagnostic combination of species.

Instead of using phytosociological nomenclature (Barkman *et al.* 1976) we used the scientific names without suffixes for naming vegetation units. Plant orders, alliances and associations were named using the generic and specific names of two dominant species from the diagnostic combination of species for that association, *e.g.*, the Tsuga mertensiana – Vaccinium membranaceum plant association. Plant subassociations were named by adding a colon (:) to the association name, followed either by the term 'typic' (to represent what we believed to be the central concept of that association) or the name of one diagnostic species, *e.g.*, the Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis plant subassociation. All units based on the synthesis of <10 sample plots were considered tentative.

Similarity and Spectral Analysis

Using VTAB (Emanuel 1999), we compared floristic similarities between pairs of vegetation units using Sørenson's index based on presence/absence of species (Equation 3.1.1, Magurran 1988), as well as on species cover (Equation 3.1.2, Qian *et al.* 1997). The presence/absence index is a simple but effective measure of the number of species shared between two vegetation units. Both indices enable the comparison of floristic similarity between vegetation units.

Equation 3.1.1. $SI = \dfrac{2c}{(a+b)}$, where a = the number of species in the first unit,
b = the number of species in the second unit, and
c = the number of species common to both units.

Equation 3.1.2. $SI = \dfrac{2C}{(A+B)}$, where A = the cover sum of all species in the first unit,
B = the cover sum of all species in the second unit, and
C = the sum of the lower of the two cover values for the species common to both units.

To provide a simple means for characterizing the vegetation of a group of plots complementary to tabular analysis, VTAB-assisted 'spectral analysis' was carried out (Mueller-Dombois & Ellenberg 1974: 315-319). Spectral analysis was performed on indicator species groups for climate (CL), soil moisture (SMR), and soil nutrients (SNR), and on life forms (LF) (coniferous trees, broad-leaved trees, evergreen shrubs, deciduous shrubs, ferns, graminoids, herbs, mosses, liverworts, lichens and dwarf woody plants) (Klinka *et al.* 1989). Spectra presenting the relative frequency of each life form (or indicator species group) were constructed for each vegetation or site unit. Relative frequencies were calculated using Equation 3.1.3 (Klinka *et al.* 1996). This means that the plots were not standardized, *i.e.*, plots with a greater total vegetation cover or indicator species cover contribute relatively more to the spectrum of the vegetation or site unit.

Equation 3.1.3. $F_j = \dfrac{\sum\limits_{i=1}^{n} C_i}{\sum\limits_{j=1}^{m} \sum\limits_{i=1}^{n} C_{ij}}$, where F_j = relative frequency (%) of species group j (j = 1,2,3...m) for attribute LF (m= 12), CL (m= 6), SMR (m= 6), SNR = (m= 3); and

C_i = midpoint percent cover value of species i (i= 1,2,3...n).

Zonal (Climatic) Classification

Biogeoclimatic or zonal units represent categories of geographically adjacent local ecosystems that are located within the sphere of influence of a particular regional climate. Zonal classification within the framework of the BEC system uses the zonal concept and the vegetation of zonal (local) ecosystems in the late seral stages to organize regional ecosystems into a hierarchy of zonal units in which the subzone is the basic unit. The portion of a plant association representing the climatic climax vegetation (i) defines a subzone, and (ii) differentiates it from all other subzones of a zone. The distribution of the included zonal ecosystems delineates the geographical extent of the subzone.

Floristically similar subzones are grouped into zones, which are characterized by a plant order circumscribing all plant associations used to differentiate subzones based on plant subassociations. As a subzone may exhibit within its area a more or less apparent climatic variation, which is usually manifested in some vegetation features, it may be divided into variants. Nomenclature for zones, regions, and formations follows Krajina (1965 *et seq.*). We named the subzones by adding two adjectives denoting climatic regimes to the name of a zone; the precipitation and continentality regimes, and sometimes the vegetation physiognomy were used for naming coastal subzones (*e.g.*, Moist Maritime – Submaritime Parkland MH (MHmm-sp) subzone). Variants are named by adding a geographic adjective to the name of a subzone (*e.g.*, Moist Submaritime MH (MHms) variant).

Site Classification

Site units represent classes of ecologically-equivalent sites which, regardless of the actual vegetation, have the same or equivalent environmental properties, *i.e.*, the same or very similar site quality, and hence, the same potential to support a certain vegetation. The basic unit of site classification is site association. Ideally, assuming 1:1 correspondence, a site association is derived from a late seral, near-climax, or climax plant association or subassociation. This relationships holds true providing that the framed site associations represent exclusive classes, *i.e.*, they can be differentiated by a specific range of climatic regimes (represented by biogeoclimatic variants or subzones), soil moisture, nutrient, and aeration regimes, and, occasionally, by additional environmental factors which directly influence vegetation. A climatically uniform portion of a site association is a site series; an edaphically uniform portion of a site association is a site type. Site series are framed by dividing a site association according to its range within biogeoclimatic variants or subzones; site types are framed by dividing a site association according to one or more topographic or soil properties thought to affect ecosystem response to the environment or management activities.

We named site associations by the common names of one or two dominant tree species and an indicator plant species, or life form, which is expected to be nearly always present on the sites represented by the site association (*e.g.*, the SbSw - Common Mitrewort site association). Tree species names were abbreviated using the standard symbols of the BC Ministry of Forests (Hm = mountain hemlock; Yc = Alaska yellow-cedar; Ba = Pacific silver fir, Bl = subalpine fir, Ss = Sitka spruce). The subdivisions of site association based on climate, the site series, were named by prefixing the symbol of a biogeoclimatic subzone or variant to the name of a site association, *e.g.*, MHmm/HmBa – Blueberry site series. The subdivisions of site associations based on edaphic factors, the site types, were named by modifying the name of a site association by one or two diagnostic adjectives, *e.g.*, HmBa – Blueberry/organic site type. We used the diagnostic adjective typic for the site type that is thought to represent the central edaphic concept of the site association, while the other adjectives are intended to denote aberrant edaphic properties.

The classification is presented in the following order: zonal units, vegetation units, and site units. This sequence allows the organization and description of ecosystems in order from the regional to local level of integration, thus eliminating redundancy. Standardized tables are included to supplement the description. Tables are structured along a gradient of increasing precipitation or soil moisture from left to right or from top to bottom. Each delineated ecosystem unit is briefly described by its vegetation and environmental features, with floristic details given in diagnostic tables, and environmental details given in summary environmental tables.

3.2 ZONAL CLASSIFICATION

Many ecological classifications organize ecosystems into a regional climate framework. Some classifications are based on the results of climatic analysis (*e.g.*, Rausher 1984), while others apply the zonal or climatic climax concept to delineate regional climates (*e.g.*, Krajina 1959). Using the zonal concept, Krajina (1959, 1969) framed 4 biogeoclimatic zones in coastal BC, among them the MH zone. Each zone represents a unique region that is assumed to be influenced by the same type of climate as it features the same type of climatic climax vegetation on zonal sites. To verify this assumption and to place the MH zone in context with the other zones, we compared the zonal vegetation, using tabular and ordination techniques, and climates of the four coastal zones: Coastal Douglas-fir (CDF), Coastal Western Hemlock (CWH), Mountain Hemlock (MH), and Alpine Tundra (AT).

Coastal Biogeoclimatic Zone

The floristic comparison showed that the MH zone is well segregated from the adjacent CWH and AT zones, but the diagnostic species of each of these zones are found in the adjacent zones near the borders, further corroborating the position of the MH zone in the middle of an environmental gradient. For example, the differential species for the MH zone, *Coptis aspleniifolia*, *Rubus pedatus*, *Tsuga mertensiana*, and *Vaccinium ovalifolium* (Table 3.2.1), may occur in the CWH zone near its upper elevation limit, and *Hylocomium splendens* and *Tsuga heterophylla* (the differential species for the CWH zone) may occur within the MH zone near its lower elevation limit. Analogously, *Tsuga mertensiana* may grow as a krummholz in the AT zone near its lower elevation limit; and a host of differential species for the AT zone may occur in the MH zone near its upper elevation limit.

Klinka *et al.* (1991) performed a principal component analysis (PCA) on the diagnostic species for the four coastal biogeoclimatic zones. The first two PCA axes accounted for 41% of the total variance, and all 28 diagnostic species (Table 3.2.1) were found to be significantly correlated with either the first, the second, or both axes. The diagnostic species for the CDF and CWH zones were strongly correlated with the first axis, and those diagnostic for the MH and AT zone were strongly correlated with the second axis. (Figure 3.2.1). The 95% confidence ellipses obtained from the PCA ordination of the 633 relevés showed that (i) the CDF zone was almost completely separated form the other zones along the first axis, (ii) the AT zone was well separated from the CWH and MH zones along the second axis, and (iii) the CWH and MH zones overlapped. Considering the number of diagnostic species for the zones (Table 3.2.1) and climatic properties (Table 3.2.2), the PCA ordination can be interpreted as follows: the CDF zone represents a discrete ecosystem, while the CWH, MH, and AT zones represent floristically-defined segments along an elevation and climatic gradient.
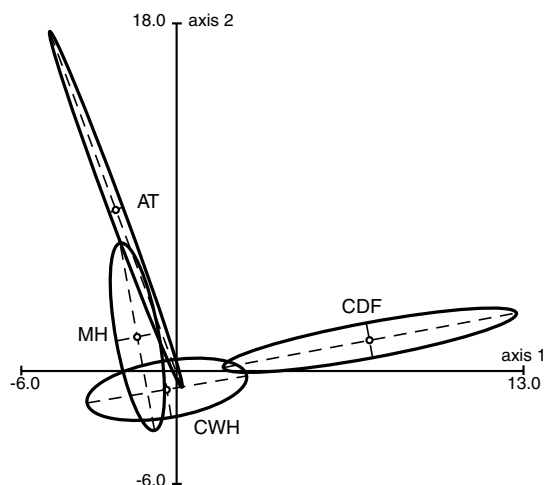
Figure 3.2.1. Ordination of relevés along the first two axes of PCA on diagnostic species showing centroids and 95% confidence ellipses for the CDF, CWH, MH, and AT zones (from Klinka *et al.* 1991).

Table 3.2.1. Diagnostic combinations of species used to differentiate between the Coastal Douglas-fir (CDF), Coastal Western Hemlock (CWH), Mountain Hemlock (MH), and Alpine Tundra (AT) zones (from Klinka *et al.* 1991).

Biogeoclimatic zone		CDF		CWH		MH		AT	
Number of plots		83		1009		187		20	
Biogeoclimatic zone and species	Diagnostic value[1]	Species presence[2] and significance[3]							
Coastal Douglas-fir (CDF) and Coastal Western Hemlock (CWH) zones									
Thuja plicata	(d)	IV	5	IV	5	I	1		
Vaccinium parvifolium	(d)	IV	2	IV	3	II	1		
Coastal Douglas-fir (CDF) zone									
Abies grandis	(d)	IV	5	I	+				
Acer macrophyllum	(d)	III	3	I	+				
Achlys triphylla	(d)	III	3	I	1	I	+		
Cornus nuttallii	(d)	III	3	I	+				
Festuca subulata	(d)	IV	1	I	+				
Gaultheria shallon	(d,cd)	V	6	II	5	I	+		
Holodiscus discolor	(d)	IV	5	I	+				
Lonicera ciliosa	(d)	IV	1	I	+				
Mahonia nervosa	(d,cd)	V	7	I	2				
Polystichum munitum	(d)	IV	2	II	1	I	+		
Pseudotsuga menziesii	(d,cd)	V	8	III	5	I	+		
Pteridium aquilinum	(d)	IV	3	I	1	I	+		
Rosa gymnocarpa	(d,c)	V	2	I	+				
Rubus ursinus	(d,d)	V	3	I	+				
Kindbergia oregana	(d,cd)	V	6	II	3	I	+		
Symphoricarpus albus	(d)	III	2	I	+				
Symphoricarpus hesperius	(d)	III	4	I	+				
Trientalis latifolia	(d,c)	V	3	I	+				
Coastal Westen Hemlock (CWH) zone									
Hylocomium splendens	(d,cd)	III	4	V	5	III	3		
Tsuga heterophylla	(d,cd)	I	2	V	7	III	4		
Mountain Hemlock (MH) zone									
Coptis aspleniifolia	(d)			I	+	III	1		
Rubus pedatus	(d)			II	2	IV	2		
Tsuga mertensiana	(d,cd)			I	2	V	6	II	2
Vaccinium ovalifolium	(d)			II	3	IV	3		
Alpine Tundra (AT) zone									
Barbilophozia floerkei	(d)			I	+	I	1	III	4
Cassiope mertensiana	(d,cd)					II	3	V	7
Luetka pectinata	(d)					II	2	IV	3
Lycopodium sitchense	(d)					I	+	III	3
Phyllodoce empetriformis	(d,cd)			I	+	II	4	V	7
Rhacomitrium heterostichum	(d)			I	+	I	+	III	3
Vahlodea atropurpurea	(d)					I	+	III	1

1 Species diagnostic values: d = differential, dd = dominant differential, cd = constant dominant (Pojar *et al.* 1987).

2 Species presence classes (the percentage of plots in which the species occurs): I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%.

3 Species significance classes and the corresponding mid-point and range (in parentheses) of cover: + = 0.2 (0.1-0.3), 1 = 0.7 (0.4-1.0), 2 = 1.6 (1.1-2.1), 3 = 3.6 (2.2-5.0), 4 = 7.5 (5.1-10.0), 5 = 15 (10.1-20.0), 6 = 26.5 (20.1-33.0), 7 = 41.5 (33.1-50.0), 8 = 60 (50.1-70.0), 9 = 85 (70.1-100).

Table 3.2.2. Means and standard deviations (in parentheses) of selected climatic properties for the CDF, CWH, MH, and AT zones (from Klinka *et al.* 1991).

Property	CDF	CWH	MH[1]	AT[1]
Mean annual precipitation (mm)	1233 (368)	2228 (713)	2620 (578)	2706 (555)
Mean precipitation April-Sept. (mm)	289 (98)	611 (227)	632 (114)	647 (65)
Mean ppt. of the driest summer month (mm)	30 (12)	63 (24)	62 (13)	70 (8)
Mean ppt. of the wettest winter month (mm)	210 (64)	350 (108)	414 (107)	434 (110)
Mean annual temperature (°C)	9.6 (0.5)	7.9 (1.6)	3.0 (1.1)	0.3 (0.9)
Mean temperature of the warmest month (°C)	17.0 (0.8)	15.6 (1.7)	11.1 (1.1)	9.2 (0.8)
Mean temperature of the coldest month (°C)	2.3 (1.0)	0.2 (3.0)	-5.1 (1.7)	-8.9 (2.7)
Number of months with mean temperature >10 °C	5.5 (0.5)	4.7 (0.8)	1.7 (0.9)	0.1 (0.4)
Index of continentality[2]	12 (3)	13 (7)	16 (3)	20 (7)

1   All values given for the AT and MH zones were extrapolated from selected base stations in the CWH zone.

2   Index of continentality, $IC = \left(1.7\dfrac{(meanT_{July} - meanT_{Jan})}{\sin DegreesLatitude}\right) - 20.4$

where T is temperature (°C) (Rose and Grant 1976).

The boundaries between the CDF, CWH, MH, and AT zones signify abrupt vegetation changes that occur in response to abrupt climatic changes in the coastal mountains. At 50°N latitude, above approximately 1500 m elevation scattered clumps of trees in the MH zone give way to krummholz, low shrub, and heath (dwarf evergreen shrub) communities under the influence of an alpine tundra climate. Below 1500 m scattered clumps of trees occur, which increase with decreasing elevation until approximately 1000 m, where they merge with the more continuous mountain hemlock forest. This continuous forest is under the influence of a maritime subalpine boreal climate with deep snow cover that protects the soil from frost. Snow depth in the AT zone is generally less than in the MH zone. Lower temperatures, however, retard the melting rate of snow in alpine ecosystems so that snow duration critically influences alpine vegetation. Moving eastward, the subalpine climate becomes more continental and the soil freezes before deep snow accumulates. Gradually mountain hemlock, Pacific silver fir, and Alaska yellow-cedar are replaced by Engelmann spruce and subalpine fir, and the MH zone is replaced by the Engelmann Spruce – Subalpine Fir (ESSF) zone.

Snow depth and duration have less influence on the vegetation in the CWH and CDF zones at elevations below approximately 1000 m (Brooke *et al.* 1970). The CWH zone coincides with the core distributional area of coastal Douglas-fir, Sitka spruce, western redcedar, and western hemlock. Western hemlock is nearly absent in the CDF zone, where the mean precipitation of the driest month of summer is <30 mm, but in the CWH zone, where the mean precipitation of the driest month of summer is >30 mm, this shade-tolerant species has the potential to dominate the tree stratum on zonal sites.

It appears that temperature-related variables best summarize the climatic differences among the zones, with temperature decreasing in order from the CDF through AT zones (Table 3.2.2). Precipitation-related variables

segregate the CDF zone from the CWH zone, the former characterized by a dry cool mesothermal climate, the latter by a wet cool mesothermal climate. The mean annual range of temperature (*i.e.*, the mean temperature of the warmest month minus that of the coldest month) is only 10°C in the CDF and CWH zones, the smallest for regional climates in Canada (Schaefer 1986). The mean annual temperature in the CDF zone is among the highest in Canada, and heavy precipitation makes the CWH, MH and the coastal portion of the AT zone by far the wettest part of Canada.

Subzones and Variants of the Mountain Hemlock Zone

Using tabular and spectral analyses we compared the relevés from zonal sites for similarities and differences in their species composition and in the relative abundance of various plant groups. A climatic comparison was not done due to the lack of climatic data and to avoid extrapolation of data from submontane weather stations. The tabular analysis showed that it was possible to differentiate (1) between hypermaritime, maritime and submaritime units, (2) between parkland and forested subzones within each continentality stratum, and (3) between windward (maritime) and leeward (submaritime) variants of both the parkland and forested subzone within the maritime and submaritime strata (Tables 3.2.3, 3.2.4, and 3.2.5).

Taking into consideration the climatic and physiognomic differences (discontinuous *versus* continuous forest cover) we delineated four subzones (Table 3.2.3). Unlike the previous classification (Meidinger and Pojar 1991; Green and Klinka 1994), a small number of plots in the present analysis could not support framing variants for the parkland and forested hypermaritime subzones; therefore these two subzones were not further subdivided. Considering the large number of plots within both the maritime and submaritime climates, we framed two variants for each of the parkland and forested subzones despite the small number of diagnostic species for each variant. We suggest that these minor floristic differences along the longitudinal gradient reflect climatic differences between the maritime (more windward) and submaritime (less leeward) variants. It may be that the floristic contrast in zonal ecosystems (and perhaps the climatic contrast) between continentality strata diminishes with increasing altitude.

Table 3.2.3. Synopsis of delineated subzones and variants of the MH zone indicating levels of generalization and relationships. Zonal vegetation units used to frame subzones and variants are given in parentheses.

Code	Subzone
	Variant
MHwhp	**Wet Hypermaritime Parkland MH**
	(111 Tsuga mertensiana – Cassiope stelleriana association)
MHwh	**Wet Hypermaritime Forested MH**
	(121a Tsuga mertensiana – Vaccinium ovalifolium: typic subassociation)
MHmm-sp	**Moist Maritime – Submaritime Parkland MH**
	(210 Tsuga mertensiana – Phyllodoce empetriformis alliance)
MHmmp	Moist Maritime Parkland MH
	(211 Chamaecyparis nootkatensis – Phyllodoce empetriformis association)
MHmsp	Moist Submaritime Parkland MH
	(212 Abies lasiocarpa – Phyllodoce empetriformis association)
MHmm-s	**Moist Maritime – Submaritime Forested MH**
	(220 Tsuga mertensiana – Vaccinium membranaceum association)
MHmm	Moist Maritime Forested MH
	(222a Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis subassociation)
MHms	Moist Submaritime Forested MH
	(222b Tsuga mertensiana – Vaccinium membranaceum: Pleurozium schreberi subassociation)

All vegetation units used to derive zonal units belong to the *Tsuga mertensiana* order (see Section 3.3 VEGETATION CLASSIFICATION - Forested Ecosystems on page 38). The species that were common to all zonal vegetation units were: *Tsuga mertensiana*, *Abies amabilis* (except on Queen Charlotte Islands), *Vaccinium ovalifolium*, *Rubus pedatus*, *Rhytidiopsis robusta*, and *Dicranum fuscescens* (Table 3.2.5). Compared to the maritime and submaritime units, the hypermaritime subzones lack *Vaccinium membranaceum,* and *Abies amabilis* is absent (Queen Charlotte Islands) or infrequent (coastal mainland). On the other hand, they feature a high presence of *Chamaecyparis nootkatensis* and a suite of low-elevation cool mesothermal species (*Blechnum spicant*, *Coptis aspleniifolia*, *Cornus canadensis*, *Hylocomium splendens*, *Plagiothecium undulatum*, and *Rhytidiadelphus loreus*, Tables 3.2.4 and 3.2.5). Within each continentality stratum, the parkland and forested subzones were well segregated. The hypermaritime parkland subzone had a significantly lower presence of alpine and upper subalpine species (*Cassiope* spp., *Luetkea pectinata*, *Phyllodoce empetriformis*, *Rhododendron albiflorum* and *Vaccinium deliciosum*) than the maritime and submaritime parkland subzone, and the hypermaritime forested subzone featured again a suite of low-elevation species, in particular, *Picea sitchensis*, *Tsuga heterophylla*, and *Vaccinium parvifolium*, which are absent or rare in the maritime forested subzone. The floristic differences between the maritime (windward) and submaritime (leeward) variants consisted mainly of a higher presence of *Chamaecyparis nootkatensis* in the maritime, and *Abies lasiocarpa* in the submaritime variant (Tables 3.2.4 and 3.2.5).

Table 3.2.4. Diagnostic combinations of species for zonal vegetation units used to delineate subzones and variants in the Mountain Hemlock zone. Numerical symbols for biogeoclimatic and vegetation units as in Table 3.2.3.

Zonal vegetation unit		111	121a	211	212	222a	222b
Biogeoclimatic unit		whp	wh	mmp	msp	mm	ms
Number of plots		7	26	32	22	50	92
Biogeoclimatic unit and species	**Diagnostic value[1]**	Species presence[2] and species significance[3]					
Wet Hypermaritime Mountain Hemlock (MHwh) subzones							
Blechnum spicant	(d)	IV 3	V 2	I h		II +	I h
Chamaecyparis nootkatensis	(d)	IV 6	IV 7	V 6	I 1	IV 6	I 3
Coptis aspleniifolia	(d)	V 3	V 3			I +	I h
Cornus canadensis	(d)	III 3	III 1	I 1		II 2	II 3
Hylocomium splendens	(d)	IV 5	V 6	I +	I +	I 4	II 4
Plagiothecium undulatum	(d)	III 3	IV 2	I t		I +	I h
Rhytidiadelphus loreus	(d)	V 6	V 7	I 2		III 5	II 4
Veratrum viride	(d)	III 4	III 3	I +	II 1	I h	I h
Wet Hypermaritime Parkland Mountain Hemlock (MHwhp) subzone							
Abies amabilis	(d)	III 4	I +	V 6	IV 6	V 7	V 7
Cassiope stelleriana	(d)	IV 6	I 1		I 2		
Cladina rangiferina	(d)	III 2		II 3	I 3	I h	I +
Fauria crista-galli	(d)	III 1	I +			I h	I t
Luetkea pectinata	(d)	III 4		III 3	IV 5		I +
Pleurozium schreberi	(d)	III 4		II 4	I +	I +	III 6
Wet Hypermaritime Forested Mountain Hemlock (MHwh) subzone							
Huperzia selago	(d)	I h	IV 2				
Listera caurina	(d)		III 2	I h		II 1	I h
Listera cordata	(d)	II 2	V 3	I h	I h	I +	I +
Lycopodium clavatum	(d)	I h	III 2			I h	I h
Menziesia ferruginea	(d)		III 3	II 4	II 4	III 4	IV 5
Moneses uniflora	(d)	I h	III +	I h			I h
Pellia neesiana	(d)	I h	III 3			I h	
Picea sitchensis	(d)	I 2	IV 5				I h
Rhizomnium glabrescens	(d)	I h	IV 4	I h		I 1	I +
Rhytidiopsis robusta	(dd)	III	III 6	V 5	II 3	V 7	IV 7
Scapania bolanderi	(d)	II 5	V 6			I +	I +

Zonal vegetation unit		111	121a	211	212	222a	222b
Biogeoclimatic unit		whp	wh	mmp	msp	mm	ms
Number of plots		7	26	32	22	50	92
Biogeoclimatic unit and species	**Diagnostic value[1]**	**Species presence[2] and species significance[3]**					
Streptopus roseus	(d)	II 1	IV 3	I +	I +	I h	I +
Tsuga heterophylla	(d)	II 3	V 7	I h		IV 5	III 5
Vaccinium parvifolium	(d)	I 2	IV 3			I +	I +

Moist Maritime – Submaritime Mountain Hemlock (MHmm-s) subzones

Species	Diag.	111	121a	211	212	222a	222b
Abies amabilis	(d)	III 4	I +	V 6	IV 6	V 7	V 7
Vaccinium membranaceum	(d)			V 6	V 6	IV 5	IV 6
Sorbus sitchensis	(ic)			III 2	II 3	I +	II 3
Orthilia secunda	(ic)			I t	II 3	III 2	II 2

Moist Maritime – Submaritime Parkland Mountain Hemlock (MHmm-sp) subzone

Species	Diag.	111	121a	211	212	222a	222b
Cassiope mertensiana	(d)	II 4		V 6	IV 6	I h	I h
Luetkea pectinata	(d)	III 4		III 3	IV 5		I +
Phyllodoce empetriformis	(d)	II 6		V 6	V 6	II 2	I 1
Rhododendron albiflorum	(ic)			II 6	III 6	II 3	II 4
Vaccinium deliciosum	(ic)			III 5	II 4		I 1

Moist Maritime Parkland Mountain Hemlock (MHmmp) variant

Species	Diag.	111	121a	211	212	222a	222b
Chamaecyparis nootkatensis	(d)	IV 6	IV 7	V 6	I 1	IV 6	I 3
Rhytidiopsis robusta	(d)	III 4	III 6	V 5	II 3	V 7	IV 7

Moist Submaritime Parkland Mountain Hemlock (MHmsp) variant

Species	Diag.	111	121a	211	212	222a	222b
Abies lasiocarpa	(d)			I 2	IV 6	I h	II 5
Dicranum fuscescens	(d)	III 4	III 3	II 6	IV 6	II 5	III 6

Moist Maritime – Submaritime Forested Mountain Hemlock (MHmm-s) subzone

Species	Diag.	111	121a	211	212	222a	222b
Menziesia ferruginea	(d)		III 3	II 4	II 4	III 4	IV 5
Rhytidiopsis robusta	(dd)	III 4	III 6	V 5	II 3	V 7	IV 7
Rubus pedatus	(dd)	IV 3	III 2	III 3	III 2	IV 5	IV 5
Tsuga heterophylla	(d)	II 3	V 7	I h		IV 5	III 5
Vaccinium ovalifolium	(dd)	III 5	IV 6	IV 5	III 6	V 7	V 7

Moist Maritime Forested Mountain Hemlock (MHmm) variant

Species	Diag.	111	121a	211	212	222a	222b
Chamaecyparis nootkatensis	(d)	IV 6	IV 7	V 6	I 1	IV 6	I 3

Moist Submaritime Forested Mountain Hemlock (MHms) variant

Species	Diag.	111	121a	211	212	222a	222b
Barbilophozia floerkei	(d)			III 4	III 3	I 2	III 5
Pleurozium schreberi	(d)	III 4		II 4	I +	I +	III 6

1 Species diagnostic values: d = differential, dd = dominant differential, ic = important companion (Pojar *et al.* 1987).

2 Species presence classes (the percentage of plots in which the species occurs): I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%.

3 Species significance classes and the corresponding mid-point and range (in parentheses) of cover: t = 0.005 (0.001-0.009), h = 0.05 (0.01 - 0.09), + = 0.2 (0.1-0.3), 1 = 0.7 (0.4-1.0), 2 = 1.6 (1.1-2.1), 3 = 3.6 (2.2-5.0), 4 = 7.5 (5.1-10.0), 5 = 15 (10.1-20.0), 6 = 26.5 (20.1-33.0), 7 = 41.5 (33.1-50.0), 8 = 60 (50.1-70.0), 9 = 85 (70.1-100).

Table 3.2.5. Differentiated (by descending order of presence from left to right) summary vegetation table for the zonal vegetation units used to delineated subzones and variants in the MH zone. Only species with a presence class ≥III in at least one unit are included.

Zonal vegetation unit Biogeoclimatic unit Number of plots Number of species	111 whp 7 57		121a wh 26 90		211 mmp 32 151		212 msp 22 88		222a mm 50 155		222b ms 92 181	
Species	**Species presence[1] and species significance[2]**											
Cassiope stelleriana	IV	6	I	1			I	2				
Cladina rangiferina	III	2			II	3	I	3	I	h	I	+
Fauria crista-galli	III	1	I	+					I	h	I	t
Thuja plicata	III	4	II	3					I	h		
Blechnum spicant	IV	3	IV	2	I	h			II	+	I	h
Coptis aspleniifolia	V	3	V	3					I	+	I	h
Cornus canadensis	III	3	III	1	I	1			II	2	II	3
Hylocomium splendens	IV	5	V	6	I	+	I	+	I	4	II	4
Plagiothecium undulatum	III	3	IV	2	I	t			I	+	I	h
Pleurozium schreberi	III	4			II	4	I	+	I	+	III	6
Veratrum viride	III	4	III	3	I	+	II	1	I	h	I	h
Luetkea pectinata	III	4			III	3	IV	5			I	+
Rhytidiadelphus loreus	V	6	V	7	I	2			III	5	II	4
Chamaecyparis nootkatensis	IV	6	IV	7	V	6	I	1	IV	6	I	3
Dicranum fuscescens	III	4	III	3	II	6	IV	6	II	5	III	6
Abies amabilis	III	4	I	+	V	6	IV	6	V	7	V	7
Rhytidiopsis robusta	III	4	III	6	V	5	II	3	V	7	IV	7
Rubus pedatus	IV	3	III	2	III	3	III	2	IV	5	IV	5
Tsuga mertensiana	V	7	V	7	V	7	V	7	V	7	V	7
Vaccinium ovalifolium	III	5	IV	6	IV	5	III	6	V	7	V	7
Huperzia selago	I	h	IV	2								
Listera caurina			III	2	I	h			II	1	I	h
Listera cordata	II	2	V	3	I	h	I	h	I	+	I	+
Lycopodium clavatum	I	h	III	2					I	h	I	h
Moneses uniflora	I	h	III	+	I	h					I	h
Pellia neesiana	I	h	III	3					I	h		
Picea sitchensis	I	2	IV	5							I	h
Rhizomnium glabrescens	I	h	IV	4	I	h			I	1	I	+
Scapania bolanderi	II	5	V	6					I	+	I	+
Streptopus roseus	II	1	IV	3	I	+	I	+	I	h	I	+
Vaccinium parvifolium	I	2	IV	3					I	+	I	+
Menziesia ferruginea			III	3	II	4	II	4	III	4	IV	5
Tsuga heterophylla	II	3	V	7	I	h			IV	5	III	5
Sorbus sitchensis					III	2	II	3	I	+	II	3
Vaccinium deliciosum					III	5	II	4			I	1
Cassiope mertensiana	II	4			V	6	IV	6	I	h	I	h
Phyllodoce empetriformis	II	6			V	6	V	6	II	2	I	1
Barbilophozia floerkei					III	4	III	3	I	2	III	5
Vaccinium membranaceum					V	6	V	6	IV	5	IV	6
Abies lasiocarpa					I	2	IV	6	I	h	II	5
Rhododendron albiflorum					II	6	III	6	II	3	II	4
Orthilia secunda					I	t	II	3	III	2	II	2

1   Species presence classes (the percentage of plots in which the species occurs): I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%.
2   Species significance classes and the corresponding mid-point and range (in parentheses) of cover: t = 0.005 (0.001-0.009), h = 0.05 (0.01 - 0.09), + = 0.2 (0.1-0.3), 1 = 0.7 (0.4-1.0), 2 = 1.6 (1.1-2.1), 3 = 3.6 (2.2-5.0), 4 = 7.5 (5.1-10.0), 5 = 15 (10.1-20.0), 6 = 26.5 (20.1-33.0), 7 = 41.5 (33.1-50.0), 8 = 60 (50.1-70.0), 9 = 85 (70.1-100).

The floristic individuality of zonal vegetation units was described by two sets of similarity indices (Table 3.2.6), with somewhat inconsistent results. When using the presence/absence index, the hypermaritime forested subzone has the highest floristic similarity to the hypermaritime parkland subzone and both are quite dissimilar from all maritime – submaritime variants; however when using the cover index, the hypermaritime forested subzone is more similar to the maritime and submaritime forested variants than to the hypermaritime parkland subzone. When using the cover index, the maritime and submaritime parkland variants have a higher similarity to each other (0.66, Table 3.2.6A) than to the maritime and submaritime forested variants, and the maritime and submaritime forested variants have a higher similarity to each other (0.55, Table 3.2.6B) than to the maritime – submaritime parkland variants. The presence/absence index, on the other hand, indicates that the maritime parkland variant is more similar to the maritime and submaritime forested variants than to the submaritime parkland variant.

Table 3.2.6. Matrix of floristic similarities for zonal vegetation units used to delineate subzones and variants in the MH zone. Higher values indicate a greater number of shared species and greater floristic similarity.

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A Sørenson (coincidence) coefficient of floristic similarity based on species presence/absence

	111 whp	121a wh	211 mmp	212 msp	222a mm
121a/wh	0.571				
211/mmp	0.336	0.324			
212/msp	0.276	0.258	0.477		
222a/mm	0.358	0.441	0.516	0.329	
222b/ms	0.319	0.384	0.542	0.446	0.565

B Cover index (Sørenson modified) of floristic similarity based on cover values

	111 whp	121a wh	211 mmp	212 msp	222a mm
121a/wh	0.259				
211/mmp	0.194	0.313			
212/msp	0.226	0.233	0.661		
222a/mm	0.167	0.458	0.491	0.354	
222b/ms	0.080	0.240	0.336	0.246	0.550

Floristic affinities between the zonal vegetation units (plant associations or subassociations) are also displayed in the life form spectra (Figure 3.2.2). In general, the same life form groups are present in each spectrum; however, the relative frequency of some of the groups varies. A low cover of deciduous shrubs (mainly *Vaccinium* spp.) separates hypermaritime from maritime – submaritime units; however, this could be due to deer overbrowsing (an important consideration on the Queen Charolottes). Compared to forested units, parkland units show a lower relative frequency of coniferous trees and a higher relative frequency of dwarf woody plants (mostly *Cassiope* and *Phyllodoce* spp.). The presence of minor differences between maritime – submaritime parkland units and between maritime – submaritime forested units suggests a high similarity of life form pattern in all of these units.
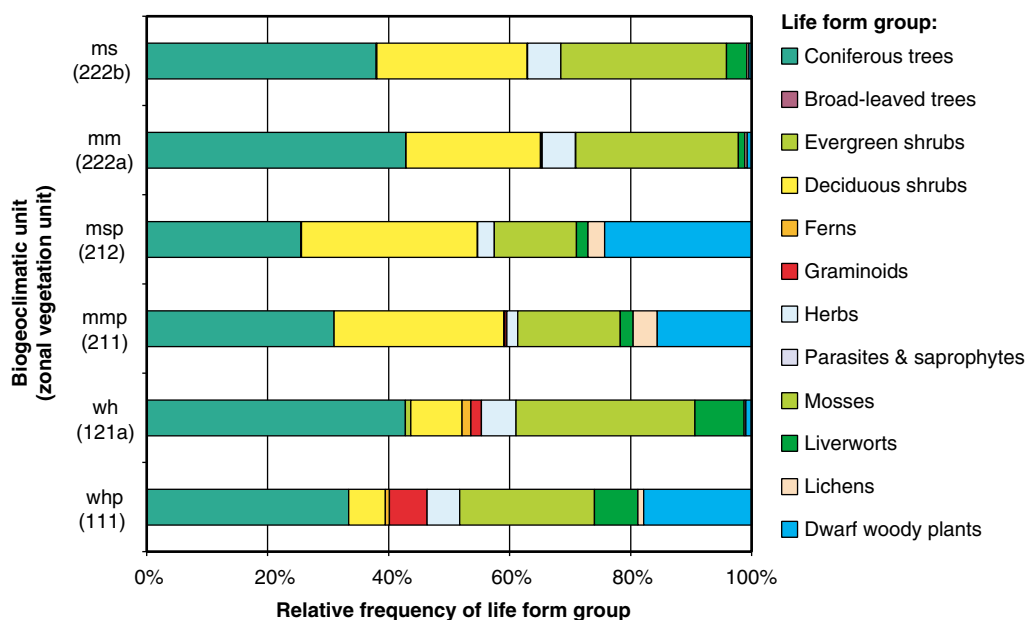
Figure 3.2.2. Life form spectra of zonal vegetation units used to delineate subzones and variants of the MH zone. Percent values denote relative frequencies; codes for biogeoclimatic and vegetation units as in Table 3.2.3.

The relationships of zonal vegetation units to climate, soil moisture and soil nutrients were examined by indicator plant analysis, which produced climatic, soil moisture, and soil nutrient spectra (Figures 3.2.3, 3.2.4, and 3.2.5). As expected, a high frequency of alpine tundra and boreal plant indicators segregated parkland units from forested units, and the lack of cool mesothermal species in the spectra separated hypermaritime from maritime – submaritime units (Figure 3.2.3). The presence of plant indicators of cool mesothermal climates in the spectra of the hypermaritime continentality stratum suggests that this climate represents a mild variation of the coastal subalpine boreal climate. Differences between maritime – submaritime parkland units and maritime – submaritime forested units were minor, but the higher frequency of either the tundra & boreal and/or the montane boreal & cool temperate indicator species groups suggests a more continental climate in the submaritime variants.

Soil moisture spectra revealed that zonal (intermediate) sites in the hypermaritime units are considerably wetter than in the maritime – submaritime units as plants indicating fresh to very moist soil moisture conditions dominate their spectra and the relative frequency of the moderately dry to fresh indicator species group was lower (Figure 3.2.4). Zonal sites in parkland units appear to be drier than those in forested units as manifested by a high frequency of species indicating moderately dry to fresh soil moisture conditions. These drier conditions may reflect the location of forested ecosystems in the parkland units on sites that are free of snow early in the year (typically elevation prominences). Differences between maritime – submaritime parkland and forested units are minor, suggesting similar soil moisture conditions in parkland and forested units as well as in the maritime and submaritime variants.

The soil nutrient spectra suggest that the soils associated with zonal sites have either very poor or poor soil nutrient regimes (a very low or low nitrogen availability) as the spectrum for each unit is dominated by indicators of nitrogen-deficient soils (Figure 3.2.5). This situation likely reflects the presence of thick, acid Mor humus forms, which often contain a high amount of decaying wood, in these relatively undisturbed ecosystems.
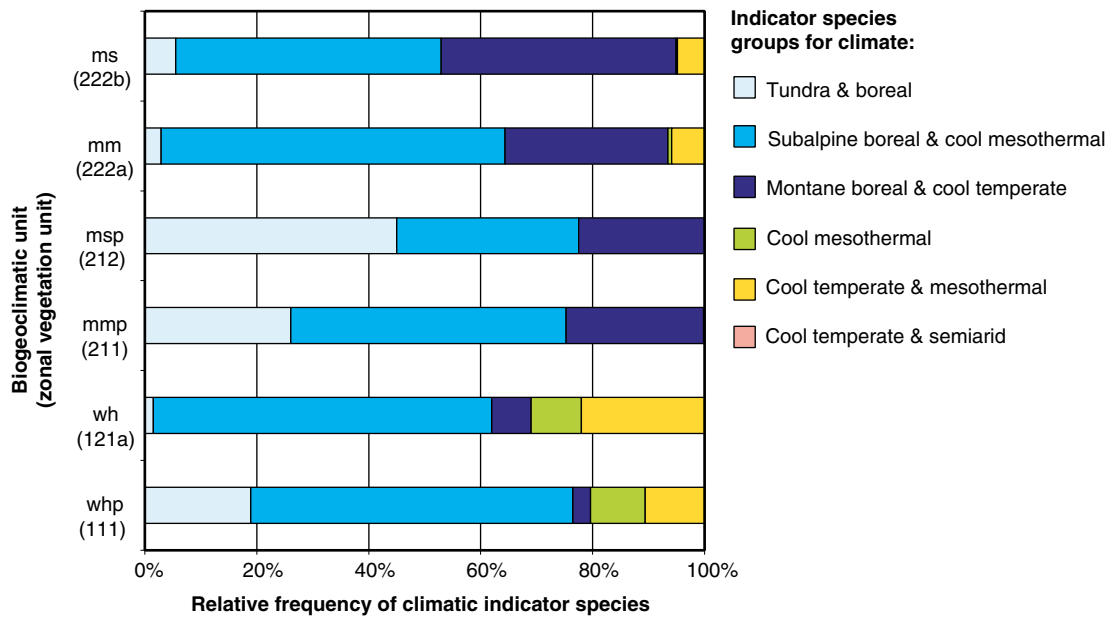
Figure 3.2.3. Climatic spectra of zonal vegetation units used to delineate subzones and variants of the MH zone. Percent values denote relative frequencies; codes for biogeoclimatic and vegetation units as in Table 3.2.3.
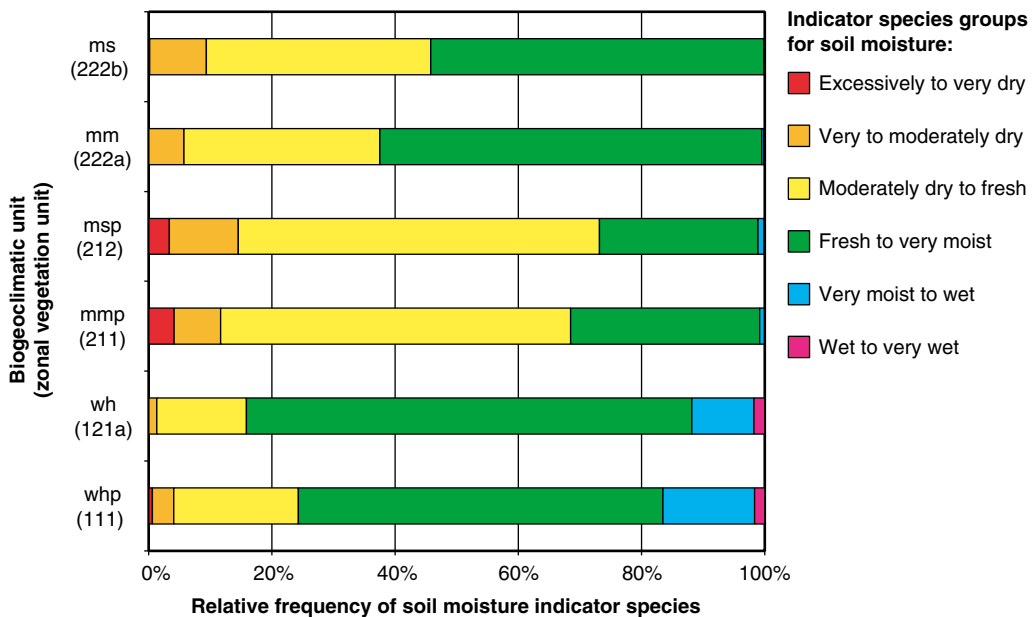
Figure 3.2.4. Soil moisture spectra of zonal vegetation units used to delineate subzones and variants of the MH zone. Percent values denote relative frequencies; codes for biogeoclimatic and vegetation units as in Table 3.2.3.
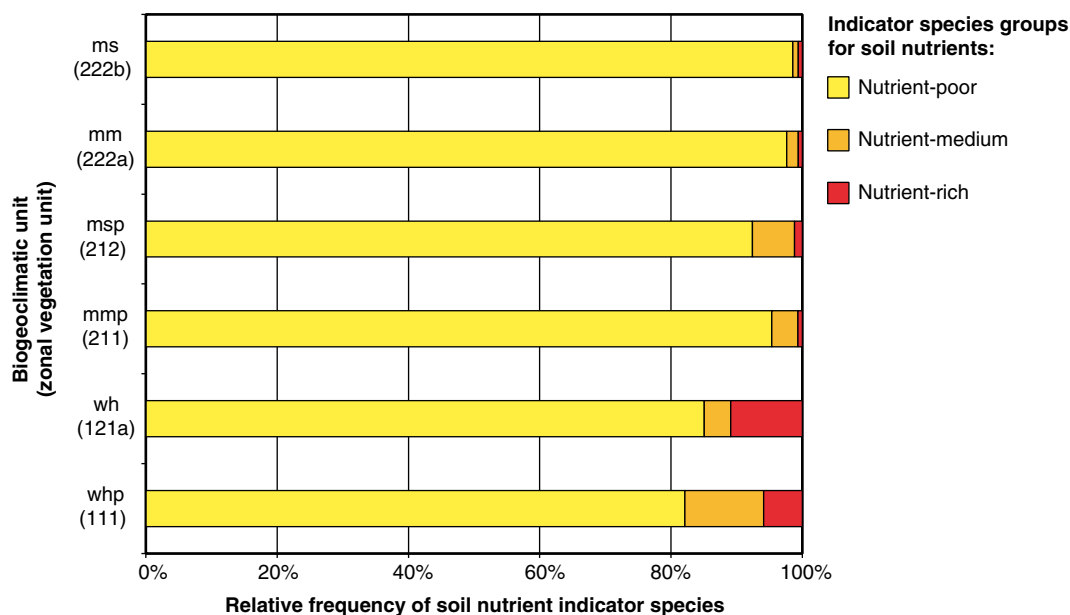
Figure 3.2.5. Soil nutrient spectra of zonal vegetation units used to delineate subzones and variants of the MH zone. Percent values denote relative frequencies; codes for biogeoclimatic and vegetation units as in Table 3.2.3.

The scattered tree cover and persistent snowpack are the most obvious characteristics of the parkland subzones. Trees grow largely on raised microsites that are free of snow for more than approximately three months. Heath, low shrub, graminoid, or forb communities that are influenced by a more persistent snowpack cover much of the remaining area of the parkland subzones (Figure 3.2.6). In contrast, forest cover is largely continuous in the forested subzones and the climate is slightly warmer. Snow depth and duration are usually less than in the parkland subzones, resulting in a longer growing season and the establishment of structurally complex forest communities (Brooke *et al.* 1970) (Figure 3.2.7).

Figure 3.2.6. Distant and close-up views of tree islands in the parkland subzone. Discontinuous forest cover and occurrence of tree islands are the principal physiognomic characteristics of the parkland subzones. At the upper elevational limits of the subzone the distance between tree islands is greater.
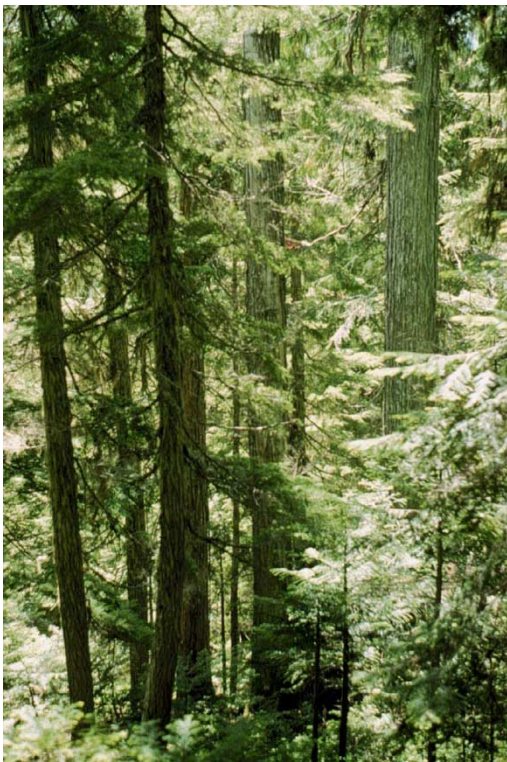
Figure 3.2.7. Nearly closed-canopy, old-growth stands of mountain hemlock with Alaska yellow-cedar on intermediate sites in the southern forested subzones. Continuous forest cover is the characteristic physiognomic feature of the forested subzones.

Zonation and Climatic Localisms

Biogeoclimatic ecosystem classification uses the zonal concept and zonal classification to delineate regional ecosystems, each influenced by different regional climate. Following the classification, the distribution of zonal units, typically biogeoclimatic zones or subzones, has been shown on small-scale (>1:500,000) maps. With the onset of site unit mapping, using scales from 1:10,000 to 1:20,000, it could be expected that these maps will show boundaries between zonal units with greater accuracy than small-scale maps. However, delineating the boundaries between zonal units on large-scale maps is not necessarily more accurate as regional climate changes gradually from one type to another, and there is likely a wide transition between climatic types.

In high-elevation landscapes, drawing the boundary between the AT and MH zones, between the parkland and forested subzones of the MH zone, and between the MH and CWH zones can be troublesome. The reason for mapping difficulties lies in the profound climatic variation that may occur over a short distance due to the variation in physiography (location of a site in the landscape), topography (position on a slope, slope gradient, and slope aspect), and elevation. Physiography, topography, and elevation affect the depth and duration of the snowpack, which in turn determine the duration of the growing season and the number of growing-degree days. The distributions of parkland and forested ecosystems follow this environmental pattern and, therefore, the boundary between parkland and forested subzones on large-scale maps does not always follow a certain elevation, but often varies greatly and discontinuously with elevation from place to place.

For a physiographically simple and uniform landscape in the Coastal Mountains the generalized climatic zonation is illustrated in Figure 3.2.8A. In the plane view, the elevation of each boundary will be consistent and it will change with aspect (cool- *versus* warm-aspect slopes), latitude, and longitude. In a physiographically complex high elevation landscape, zonation can be correspondingly complex (Figure 3.2.8B). Typically, in the MH zone, small areas (5 to 50 ha) of parkland ecosystems can be surrounded by forest ecosystems, and similarly, small areas of forest ecosystems can be surrounded by parkland ecosystems. In the plane view, neither the parkland nor the forest subzone will be shown as a consistent elevation belt, but as a mosaic of polygons of one zonal unit within another unit. The reason for such a pattern is that the gradual change in climate along the elevation gradient is disrupted by flat topography, which creates conditions conducive to greater snowpack (Figure 3.2.9). Thus, forest ecosystems may develop at higher elevations than expected (*i.e.*, within the distribution area of parkland ecosystems, on warm-aspect slopes with a warmer climate and consequently less snowpack and shorter snow duration), and parkland ecosystems may develop at a lower than expected elevation (*i.e.*, within the distribution area of forest ecosystems in basins (Figures 3.2.9A and 3.2.10) and on flat relief (plateaus, Figures 3.2.9B and 3.2.11) which are influenced by high snowpack and/or cool air drainage).
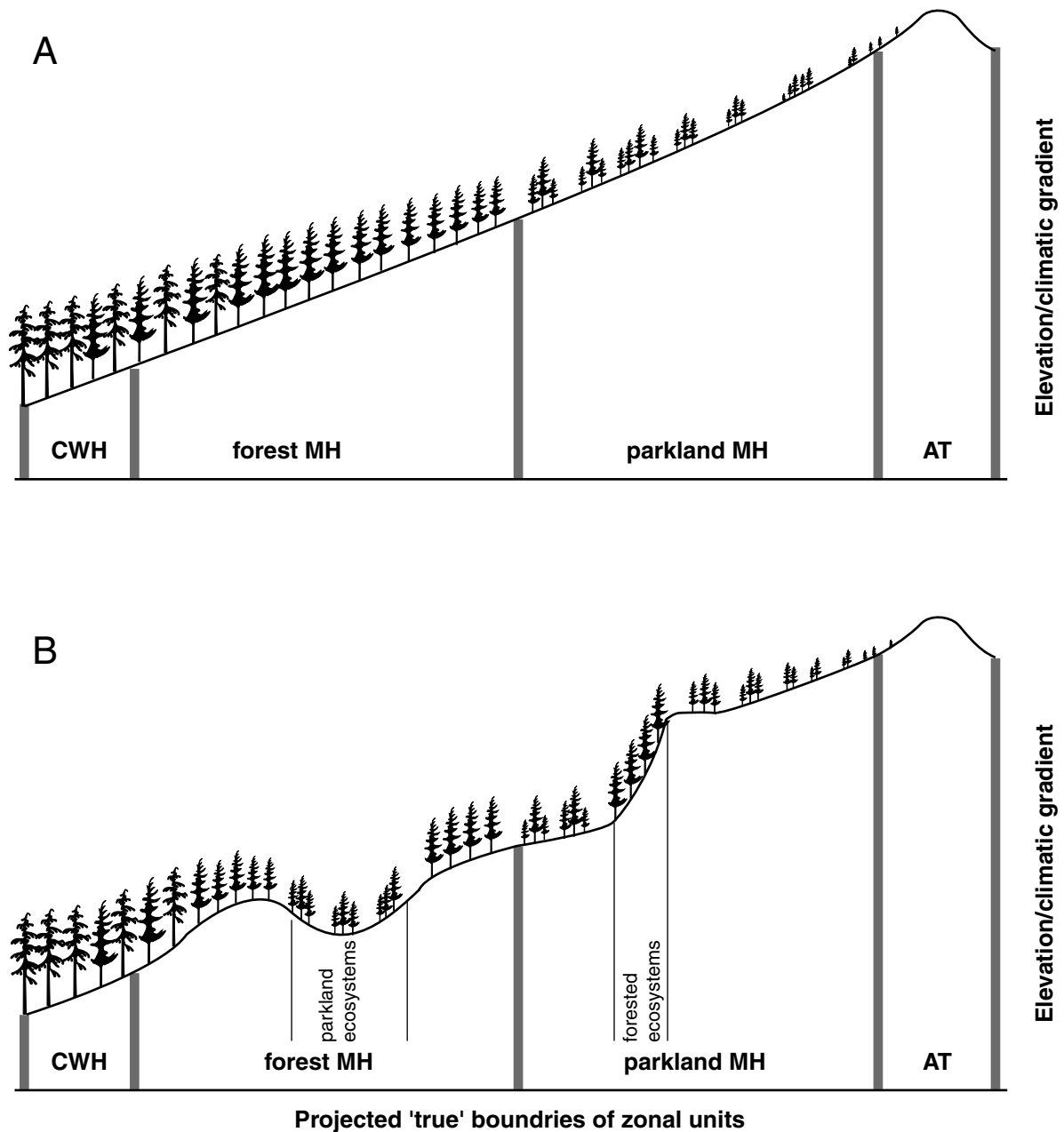
Figure 3.2.8. Generalized climatic zonation in a phyisographically simple (A) and complex (B) portion of the MH zone. Due to climatic localisms in the complex landscape, parkland ecosystems characteristic of higher elevations (cooler climate) sometimes occur at lower elevations (warmer climate), and forested ecosystems characteristic of lower elevations occur at higher elevations, than in the physiographically simple landscape.
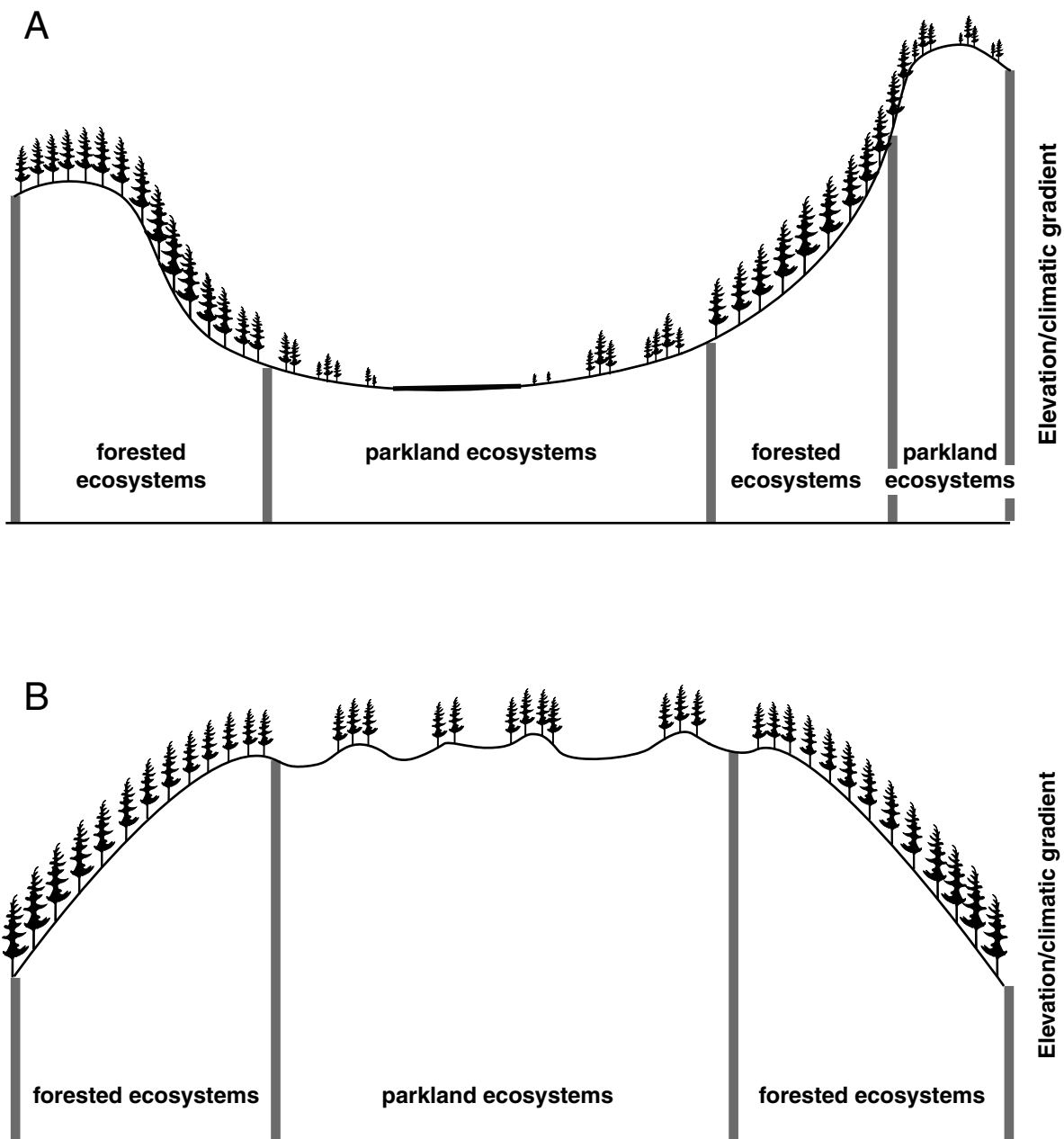
Figure 3.2.9. Profiles of two commonly occurring relief situations: (A) basins and (B) flat relief, which accumulate more snow than the surrounding slopes and support parkland communities characteristic of higher elevations within a matrix of forested ecosystems.

Figure 3.2.10. Distant and close-up images of a complex of parkland ecosystems within the limits of the forested MH subzone due to climatic localisms imposed by the presence of basins in the southern Coast Mountains.

Figure 3.2.11. Distant and close-up images of a complex of parkland ecosystems within the limits of the forested MH subzone due to climatic localisms imposed by the presence of flat relief in the southern Coast Mountains.

This situation invites a question: how does one distinguish between local and regional climates? This has the following corollary: what is the minimum area of a zonal unit? We do not offer answers to these questions, but suggest that the complexity in the distribution pattern between parkland and forest ecosystem types is due to topographic localism, and that topographic localism is the determinant of local climate. This implies that, in the MH zone, parkland ecosystems occurring as small areas within a forested subzone should be considered a part of that subzone, albeit developing under the influence of a special (cooler and high-snowpack) local climate. Similarly, forested ecosystems occurring as small areas within a parkland subzone should be considered a part of that subzone, albeit developing under the influence of a special (warmer and low-snowpack) local climate.

If we accept that these extrazonal occurrences of forested or parkland communities are due to climatic localisms, then we should consider local climate as a third gradient (in addition to soil moisture and nutrient gradients) that illustrates the relationships of ecosystems to the principal environmental factors. Such a proposal was made by Hills and Pierpoint (1960) who used three edatopic grids for each regional climate: (1) the main grid for normal local climates, (2) an auxiliary grid for warmer than normal local climates and (3) another auxiliary grid for cooler than normal local climates (see Section 3.3 VEGETATION CLASSIFICATION on page 30).

3.3 VEGETATION CLASSIFICATION

The purpose of vegetation classification is to organize local ecosystems into classes (groups) that are similar in their floristic composition and structure. Thus the delineated vegetation units represent floristically uniform groups of ecosystems. The diagnostic combinations of species are the sole differentiating characteristics used to classify ecosystems *via* plant communities into a hierarchy of vegetation units in which the plant association is the principal category. The diagnostic combination of species is a group of plant species that is more or less exclusive to a given vegetation unit, and which is used to identify plant communities (ecosystems) of that unit.

In this report, we first present the vegetation classification of non-forested communities, and then the classification of forested communities, which are included into the Tsuga mertensiana order. The classification includes synopses, diagnostic tables, differentiated summary vegetation tables, and the results of spectral analyses. The descriptions of the vegetation units used to derive site units can be found in Section 3.5 DESCRIPTION OF THE SITE UNITS starting on page 65.

Non-Forested Ecosystems

The most recent classification of alpine and subalpine non-forested communities in coastal British Columbia was developed by Brett *et al.* (2001). Therefore, in this report, we present a complete synopsis of all delineated vegetation units, but diagnosis and characterization are limited to the plant orders. These orders are characterized with respect to the main environmental features in the context of the MH parkland in Section 3.4 SITE CLASSIFICATION - Parkland MH Subzones on page 50.

Brett *et al.* (2001) defined non-forest plant communities as those where trees are permanently absent, or where they can survive only as prostrate or stunted shrubs <3 m tall (krummholz). Similar criteria have been used to define the timberline and the lower limit of the Alpine Tundra zone (*e.g.*, Arno 1966; Brooke *et al.* 1970), but we also use them to distinguish non-forest communities that develop between tree islands in the parkland subzones. The relative abundance of forest and non-forest communities is related to the snow-free period, with non-forested communities dominating above elevations where snow remains on the ground for approximately 8 or more months (Brooke *et al.* 1970).

Non-forested plant communities are characteristic of upper subalpine and alpine environments. The Alpine Tundra zone is non-forested by definition, since conditions are so harsh that tree species are unable to survive except as krummholz, or dwarf shrubs. In contrast, the MH parkland has a mosaic of non-forested and forested (tree island) communities. The progression from closed forest (at lower elevations), to tree islands, to treeless expanses with increasing elevation is closely related to the decreasing duration of growing season caused by later snowmelt. Deep winter snowpacks remain well into June on most sites and may not melt before late August on sites protected from direct sunlight, *e.g.*, bowls and cool-aspect slopes. Depending on aspect, topography, and patterns of snowmelt, the transition from closed forest to alpine tundra can be gradual, abrupt, or even discontinuous. As a result, very steep community gradients develop in direct relation to snowmelt patterns (Brooke *et al.* 1970; Franklin and Dyrness 1988). Plant communities are dominated by heath, herbs, graminoids, bryophytes, or lichens. Compared to upper subalpine communities, alpine communities include a larger percentage of open rather than closed vegetation cover.

Of the 282 relevés, all but 14 were classified into a hierarchy of vegetation units that included 13 subassociations, 30 associations, 13 alliances, and 11 orders (Table 3.3.1). As mentioned above, we present only diagnostic combinations of species and differentiated summary tables for orders (Tables 3.3.2 and 3.3.3). Although tabular analysis produced groupings that differed floristically, the diagnostic combinations of species for seven of the eleven orders included only one or two species (Table 3.3.2). These orders included: Rhizocarpon geographicum, Marsupella brevissima, Carex nigricans, Carex spectabilis, Valeriana sitchensis, Eriophorum angustifolium, and Sphagnum – Carex. In most of these cases, the weak differentiation likely reflects species-poor or single-species dominated communities, tending in some cases towards monocoenoses (populations consisting of a single plant species). Compared to forested communities, which are represented by a single plant order (Tsuga mertensiana), the floristically and environmentally diverse non-forested communities in the MH zone are represented by eleven orders.

Table 3.3.1. Synopsis of delineated vegetation units distinguished in non-forested communities in the MH zone (from Brett *et al.* 2001). Diagnosis based on <10 relevés is indicated by an asterisk (*). Citations are included for vegetation units corresponding to previous studies; the abbreviation '*n.n.*' (*nomen novum*) is included if the name has been changed.

Order
Alliance
Association
Subassociation

1 Rhizocarpon geographicum
    Rhizocarpon geographicum
        Sibbaldia procumbens*; Archer 1963 (5 plots)
        Silene acaulis*; Archer 1963 (4 plots)
        Penstemon davidsonii – Juniperus communis*; Archer 1963 (6 plots)
        Phyllodoce – Abies lasiocarpa; *n.n.*; Archer 1963 (10 plots)

2 Phlox diffusa*
    Phlox diffusa*
        Phlox diffusa* (5 plots)

3 Marsupella brevissima
    Marsupella brevissima
        Polytrichum alpinum – Marsupella brevissima*; *n.n.*; Archer 1963 (9 plots)
        Polytrichum piliferum – Marsupella brevissima*; *n.n.*; Archer 1963 (8 plots)
        Luzula wahlenbergii – Saxifraga tolmiei*; *n.n.*; Brooke *et al.* 1970 (4 plots)

4 Carex nigricans
    Carex nigricans
        Carex nigricans; Archer 1963
            Carex nigricans: typic* (6 plots)
            Carex nigricans: Polytrichum alpinum (10 plots)

5 Cassiope – Phyllodoce
    Cassiope mertensiana
        Carex spectabilis – Cassiope mertensiana; *n.n.*; Archer 1963 (10 plots)
    Cassiope mertensiana – Tsuga mertensiana
        Cassiope mertensiana – Phyllodoce empetriformis; *n.n.*; Brooke *et al.* 1970
            Cassiope mertensiana – Phyllodoce empetriformis: typic (12 plots)
            Cassiope mertensiana – Phyllodoce empetriformis: Vaccinium deliciosum (12 plots)
        Cassiope mertensiana – Tsuga mertensiana; *n.n.*; Brooke *et al.* 1970
            Cassiope mertensiana – Tsuga mertensiana: typic* (7 plots)
            Cassiope mertensiana – Tsuga mertensiana: Hippuris montana* (5 plots)
    Luetkea pectinata*
        Luetkea pectinata*; Archer 1963 (7 plots)

6 Carex spectabilis
    Carex spectabilis
        Carex spectabilis*; Archer 1963 (8 plots)
        Anaphalis margaritacea – Lupinus arcticus; Archer 1963 (12 plots)
        Oxyria digyna – Carex spectabilis* (1 plot)

7 Philonotis fontana
    Philonotis fontana
        Caltha leptosepala – Leptarrhena pyrolifolia; Brooke *et al.* 1970 (13 plots)
        Epilobium latifolium – Mimulus lewisii; Archer 1963 (10 plots)

Order
Alliance
    Association
        Subassociation

8 Valeriana sitchensis
Valeriana sitchensis
Parnassia fimbriata – Valeriana sitchensis* (5 plots)
Heracleum maximum – Valeriana sitchensis (10 plots)
Carex spectabilis – Valeriana sitchensis*; *n.n.***; Archer 1963 (5 plots)**
Sphagnum – Valeriana sitchensis* (1 plot)

9 Alnus viridis
Alnus viridis
Oplopanax horridus – Alnus viridis
    Oplopanax horridus – Alnus viridis: Rubus parviflorus* (8 plots)
    Oplopanax horridus – Alnus viridis: typic (21 plots)
Phyllodoce empetriformis – Alnus viridis* (1 plot)
Juncus ensifolius – Alnus viridis* (1 plot)
Valeriana sitchensis – Alnus viridis* (7 plots)

10 Eriophorum angustifolium
Eriophorum angustifolium
Warnstorfia exannulata – Eriophorum angustifolium*
Fauria crista-galli – Eriophorum angustifolium
    Fauria crista-galli – Eriophorum angustifolium: Empetrum nigrum* (6 plots)
    Fauria crista-galli – Eriophorum angustifolium: typic* (5 plots)
    Fauria crista-galli – Eriophorum angustifolium: Sphagnum* (4 plots)
Carex aquatilis – Eriophorum angustifolium*; *n.n.***; Brooke** *et al.* **1970 (5 plots)**

11 Sphagnum – Carex
Sphagnum – Carex
Sphagnum – Carex pluriflora
    Sphagnum – Carex pluriflora: Vaccinium uliginosum* (1 plot)
    Sphagnum – Carex pluriflora: typic *n.n.* Wade 1965 (19 plots)

Table 3.3.2. Diagnostic combinations of species for the eleven plant orders distinguished in non-forested communities in the MH zone.

Plant order	Diagnostic value[1]	1	2	3	4	5	6	7	8	9	10	11
Number of plots		25	5	21	16	53	21	23	21	38	25	20
				Species presence[2] and species significance[3]								
1 Rhizocarpon geographicum												
Phyllodoce glanduliflora	(d)	III 3		I h	I h	I 4	I 3					
Polytrichum piliferum	(ic)	III 3	I h	II 5		I 3	I 1		I h			
Umbilicaria proboscidea	(d)	III 3				I h						
Rhizocarpon geographicum	(ic)	IV 3	III +			I +						
2 Phlox diffusa												
Paxistima myrsinites	(d)		III 3							I h		
Penstemon procerus	(d)	I h	III 2			I h	I h					
Phlox diffusa	(d)		IV 6			I h						
Saxifraga occidentalis	(d)		III 2									
Selaginella wallacei	(d)		III 1									
Tortella tortuosa	(d)		III 6									
3 Marsupella brevissima												
Marsupella brevissima	(d)			V 7	II 3	I 2		I +		I h		
Saxifraga tolmiei	(d)			III 4	II 2	I h				I h		
4 Carex nigricans												
Carex nigricans	(dd)	I +	II h	IV 3	V 8	II 2	II 1	III 5	I 3		I 5	
5 Cassiope – Phyllodoce												
Barbilophozia floerkei	(d)					I 1	III 5				I 4	
Cassiope mertensiana	(dd)	II 2	I h	II 2	III 4	IV 7	I +	I h		I +	I 4	
Cladonia bellidiflora	(d)					III 2				I h		
Dicranum fuscescens	(dd)	II 2				III 6	I h	I 1				
Luetkea pectinata	(dd)	I 1	I h	II 3	III 3	V 6	III 4	II 2	II 2	I +	I +	
Lycopodium sitchense	(d)	I h			I h	III 3			I +		I +	
Phyllodoce empetriformis	(dd)	III 3		II 2	IV 3	V 7	I +	II +	I +	I 3	I +	
Tsuga mertensiana	(d)	I 3		I +	I h	III 6		I t		I h		
Vaccinium deliciosum	(d)			I t	II 1	IV 6		I h				
Vaccinium membranaceum	(d)			I t		III 3		I h				
6 Carex spectabilis												
Anaphalis margaritacea	(d)						III 6	I t		I +		
Carex spectabilis	(dd)	I 1		I +	II 3	II 1	V 7	III 4	III 5		I 3	
Lupinus arcticus	(dd)			I 2	I h	I 4	IV 7	I h	II 2			
7 Philonotis fontana												
Caltha leptosepala	(dd)					I h		III 5			I 2	
Epilobium anagallidifolium	(ic)		I h	I t	I 1	I h	I +	III 4	II +	I h		
Leptarrhena pyrolifolia	(dd)					I t		IV 7	I +	I +	I h	
Philonotis fontana	(dd)				I h			IV 7			I 4	
8 Valeriana sitchensis												
Valeriana sitchensis	(dd)					I 1	I 1	III 2	V 7	II 4		
Veratrum viride	(dd)					I h		I 2	III 5	II 3	I h	
9 Alnus viridis												
Alnus viridis	(dd)								I +	IV 7		
Athyrium filix-femina	(dd)						I h	I +	I 4	IV 6		
Oplopanax horridus	(d)									III 4		
Rubus spectabilis	(dd)								I 4	III 5		
Sambucus racemosa	(d)									III 4		
Streptopus roseus	(d)								I 2	III 4	I h	

Plant order	Diagnostic value[1]	1	2	3	4	5	6	7	8	9	10	11
Number of plots		25	5	21	16	53	21	23	21	38	25	20
		Species presence[2] and species significance[3]										

10 Eriophorum angustifolium

		1	2	3	4	5	6	7	8	9	10	11
Eriophorum angustifolium	(dd)							I h			V 7	
Fauria crista-galli	(d)										III 5	I h

11 Sphagnum – Carex

		1	2	3	4	5	6	7	8	9	10	11
Carex pluriflora	(dd)											V 7
Sanguisorba officinalis	(d)										I 2	IV 4
Sphagnum fallax	(dd)											IV 7
Sphagnum papillosum	(d)											IV 4

1 Species diagnostic values: d = differential, dd = dominant differential, ic = important companion (Pojar *et al.* 1987)

2 Species presence classes (the percentage of plots in which the species occurs): I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%

3 Species significance classes and the corresponding mid-point and range (in parentheses) of cover: t = 0.005 (0.001-0.009), h = 0.05 (0.01 - 0.09), + = 0.2 (0.1-0.3), 1 = 0.7 (0.4-1.0), 2 = 1.6 (1.1-2.1), 3 = 3.6 (2.2-5.0), 4 = 7.5 (5.1-10.0), 5 = 15 (10.1-20.0), 6 = 26.5 (20.1-33.0), 7 = 41.5 (33.1-50.0), 8 = 60 (50.1-70.0), 9 = 85 (70.1-100.0).

Table 3.3.3. Differentiated (by descending order of presence from left to right) summary vegetation table for non-forested plant orders distinguished in the MH zone. Only species present in ≥40% of the plots of at least one unit (presence class ≥III) are included. Numerical codes for orders as in Table 3.3.1.

Plant order	1	2	3	4	5	6	7	8	9	10	11
Number of plots	25	5	21	16	53	21	23	21	38	25	20
Number of plant species	59	61	40	49	137	66	125	131	194	105	12
Species	Species presence and species significance[1]										
Juniperus communis	III 6	II 6			I t						
Phyllodoce glanduliflora	III 3		I h	I h	I 4	I 3					
Polytrichum piliferum	III 3	I h	II 5		I 3	I 1		I h			
Umbilicaria proboscidea	III 3				I h						
Rhizocarpon geographicum	IV 3	III +			I +						
Phyllodoce empetriformis	III 3		II 2	IV 3	V 7	I +	II +	I +	I 3	I +	
Paxistima myrsinites		III 3							I h		
Penstemon procerus	I h	III 2			I h	I h					
Phlox diffusa		IV 6			I h						
Saxifraga occidentalis		III 2									
Selaginella wallacei		III 1									
Tortella tortuosa		III 6									
Marsupella brevissima			V 7	II 3	I 2		I +		I h		
Saxifraga tolmiei			III 4	II 2	I h				I h		
Polytrichum alpinum	I 1		IV 5	IV 6	I h						
Carex nigricans	I +	II h	IV 3	V 8	II 2	II 1	III 5	I 3	I h	I 5	
Juncus drummondii	I h		III 3	IV 3	I h	II 1	IV 2	I t	I h		
Cassiope mertensiana	II 2	I h	II 2	III 4	IV 7	I +	I h		I +	I 4	
Vahlodea atropurpurea	I h	I h	I h	III 4	IV 3	II +	II 1	I 4	I 2	I 1	
Luetkea pectinata	I 1	I h	II 3	III 3	V 6	III 4	II 2	II 2	I +	I +	
Barbilophozia floerkei				I 1	III 5					I 4	
Cladonia bellidiflora					III 2				I h		
Dicranum fuscescens	II 2				III 6	I h	I 1				
Lycopodium sitchense	I h			I h	III 3			I +		I +	
Tsuga mertensiana	I 3		I +	I h	III 6		I t		I h		
Vaccinium deliciosum			I t	II 1	IV 6		I h				
Vaccinium membranaceum			I t		III 3		I h				
Anaphalis margaritacea						III 6	I t		I +		
Hieracium gracile		I h		II +	II +	III 2	I h	I +			
Lupinus arcticus			I 2	I h	I 4	IV 7	I h	II 2			
Carex spectabilis	I 1		I +	II 3	II 1	V 7	III 4	III 5		I 3	
Caltha leptosepala					I h		III 5			I 2	
Epilobium anagallidifolium		I h	I t	I 1	I h	I +	III 4	II +	I h		
Erigeron peregrinus		II h			I +	I +	III 5	I +	I h	I h	I h
Leptarrhena pyrolifolia					I t		IV 7	I +	I +	I h	
Philonotis fontana				I h			IV 7			I 4	
Valeriana sitchensis					I 1	I 1	III 2	V 7	II 4		
Heracleum maximum								III 5	II 4		
Senecio triangularis						I h	II 3	III 5	I h		
Veratrum viride					I h		I 2	III 5	II 3	I h	
Alnus viridis								I +	IV 7		
Athyrium filix-femina						I h	I +	I 4	IV 6		
Oplopanax horridus									III 4		
Rubus spectabilis								I 4	III 5		
Sambucus racemosa									III 4		
Streptopus roseus								I 2	III 4	I h	
Eriophorum angustifolium							I h			V 7	
Fauria crista-galli										III 5	I h
Carex pluriflora										V 7	
Sanguisorba officinalis									I 2	IV 4	
Sphagnum fallax										IV 7	
Sphagnum papillosum										IV 4	

1 Species presence and significance classes as defined in Table 3.3.2.

The relative abundance of plant species stratified according to life form for the different plant orders is illustrated in life form spectra (Figure 3.3.1). In addition to floristic differences, each order can be characterized by a unique spectrum or a life form signature. The most common life form in all spectra were mosses, graminoids, and herbs; however their proportions varied. Conifers were present only in the spectrum of the Rhizocarpon geographicum (1) order, which included krummholz and dwarfed mountain hemlock communities. Broad-leaved trees were present in the spectra of the Valeriana sitchensis (8) and Alnus viridis (9) orders, which included Sitka alder and willows. Evergreen shrubs (*e.g., Juniperus communis*) and dwarf woody plants (predominantly heathers) were characteristic of the Rhizocarpon geographicum (1), Phlox diffusa (2), and Cassiope – Phyllodoce (5) orders. The proportion of graminoids was high in wetlands represented by the Carex nigricans (4), Eriophorum angustifolium (10), and Sphagnum – Carex (11) orders. Herbs were most common in several orders including Phlox diffusa (2), Carex spectabilis (6), Philonotis fontana (7), and Alnus viridis (9), which also included the highest proportion of ferns. Liverworts occurred with a high frequency only in the Marsupella brevissima (3) order. The proportion of lichens was highest in the xerophytic Rhizocarpon geographicum order.
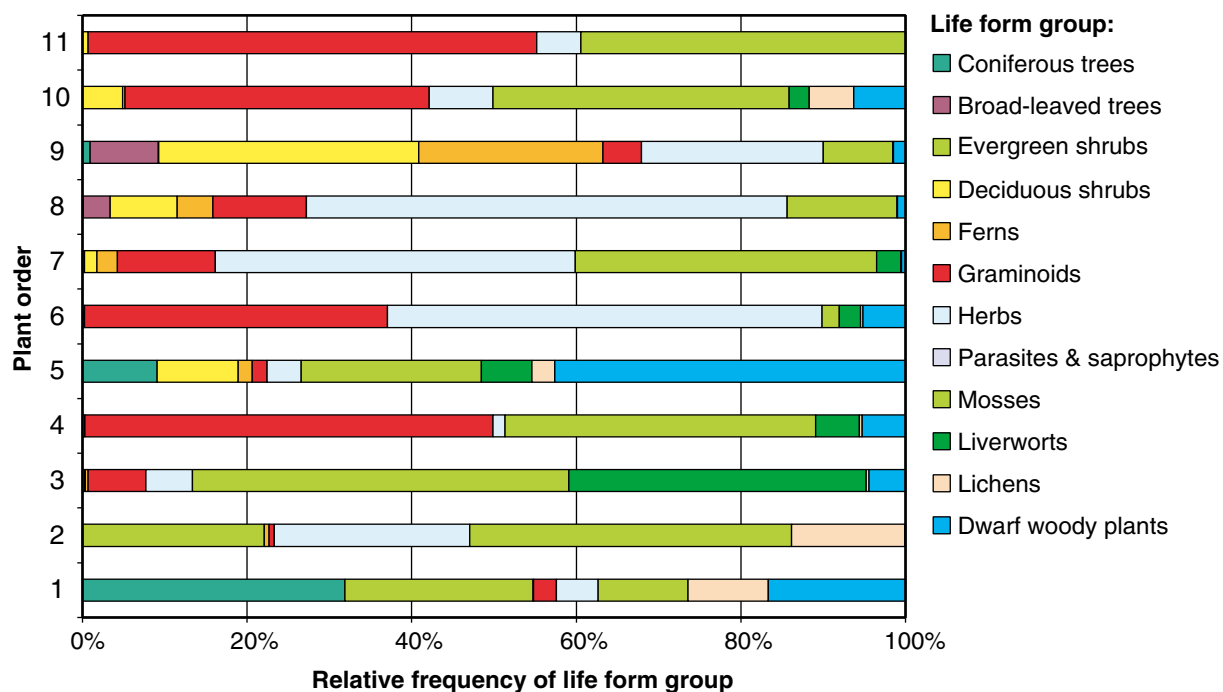
Figure 3.3.1. Life form spectra for the eleven plant orders distinguished in non-forested plant communities in the MH zone. Percent values denote relative frequencies; codes for orders as in Table 3.3.1.

The floristic individuality of the plant orders was reflected by the few Sørenson's Index values >0.40 (Table 3.3.4). The two most floristically similar pairings were the two late-snowmelt orders – Marsupella brevissima (3) and Carex nigricans (4) (SI = 0.56), and the two orders containing the greatest number of herbaceous species – Valeriana sitchensis and Alnus viridis (SI = 0.46). All pairings with the species-poor and unique Sphagnum – Carex (11) order had Sørenson's Index values SI ≤0.10. The degree of floristic similarity appeared to be related to a soil nutrient gradient. Values were all ≥0.30 for pairings between the four orders associated with poor sites, *i.e.* the Rhizocarpon geographicum (1), Marsupella brevissima (3), Carex nigricans (4), and Cassiope – Phyllodoce (5) orders. Similarly, values were all ≥0.28 within rich sites represented by the Philonotis fontana (7), Valeriana sitchensis (8), and Alnus viridis (9) orders. The Carex spectabilis (6) order occupied an intermediate position, with relatively high floristic similarities to both nutrient-poor and nutrient-rich orders. Similar relationships between floristic similarity and soil nutrient regime could not be extended to the Phlox diffusa (2), Epilobium angustifolium (10), and Sphagnum – Carex orders (11), nor could relationships as strong as these be detected between floristic similarity and soil moisture conditions.

Table 3.3.4. Matrix of floristic similarities for the non-forested plant orders delineated in the MH zone based on cover (Sørenson's modified index, Quian *et al.* 1997). Higher values indicate a greater number of shared species, *i.e.*, greater floristic similarity. Numerical codes for orders as Table 3.3.1.

Order	1	2	3	4	5	6	7	8	9	10
2	0.20									
3	0.38	0.16								
4	0.30	0.13	0.56							
5	0.42	0.24	0.32	0.37						
6	0.38	0.27	0.36	0.30	0.36					
7	0.18	0.12	0.24	0.29	0.37	0.36				
8	0.17	0.18	0.13	0.18	0.27	0.31	0.37			
9	0.08	0.14	0.10	0.09	0.19	0.21	0.28	0.46		
10	0.15	0.10	0.12	0.25	0.26	0.13	0.37	0.16	0.13	
11	0.00	0.03	0.00	0.03	0.03	0.03	0.03	0.03	0.02	0.10

Herbs and mosses represented more than half of the species (Table 3.3.5). Conifers and evergreen shrubs were the least diverse life form classes. While the proportion of herbs and mosses was relatively consistent across different plant orders, herb diversity was generally greater on richer site, and moss diversity was greatest on poorer sites. Deciduous shrubs were most diverse in the avalanche track communities of the Alnus viridis order. The diversity of lichens was greatest in the xerophytic communities of the Rhizocarpon geographicum (1) order, but was also high in the heath communities of the Cassiope – Phyllodoce (5) order. Since the number of identified plant species increases with increasing number of releves, Table 3.3.5 presents species diversity as percentage. Nevertheless, some observations can be made about the total number of species by plant order: the Alnus viridis order had the most species, including 93 herbaceous species, while the Sphagnum – Carex (11) order had the fewest species. Given that only five plots were sampled, the Phlox diffusa (2) order contained unexpectedly diverse communities.

Table 3.3.5. Species richness (percent number of species) of the non-forested plant orders delineated in the MH zone. To prevent counting shared species more than once, row totals were calculated using the combined data set. Numerical codes for orders as in Table 3.3.1.

Order	1	2	3	4	5	6	7	8	9	10	11	Total
Number of plots	25	5	21	16	53	21	23	21	38	25	20	268
Coniferous trees	5.1	0	2.5	2.0	2.9	0	2.4	1.5	3.1	0	0	1.8
Evergreen shrubs	8.5	4.9	7.5	8.2	3.6	4.5	1.6	0.8	1.5	5.7	8.3	2.0
Deciduous shrubs	1.8	0	5.0	2.0	5.8	1.5	5.6	6.9	15.5	1.9	8.3	7.7
Ferns & allies	1.7	4.9	5.0	2.0	2.2	4.5	4.0	8.4	7.2	3.8	0	5.1
Graminoids	15.3	14.8	17.5	14.3	7.3	15.2	16.0	16.0	16.0	21.0	16.7	13.2
Herbs	16.9	42.6	15.0	14.3	21.2	43.9	34.4	47.3	47.9	22.9	41.7	33.8
Mosses	27.1	23.0	30.0	32.7	24.8	18.2	25.6	14.5	6.7	31.4	25.0	21.0
Liverworts	0	0	12.5	16.3	13.9	4.5	9.6	1.5	0.5	7.6	0	7.3
Lichens	23.7	9.8	5.0	8.2	18.2	7.6	0.8	3.1	1.5	5.7	0	7.9
Total	100	100	100	100	100	100	100	100	100	100	100	100
Total species	59	61	40	49	137	66	125	131	194	105	12	491

Forested Ecosystems

At the highest level of generalization, Klinka *et al.* (1996) delineated seven plant orders that represent forested communities in coastal British Columbia, among them the Tsuga mertensiana order. This order comprises most of the forested ecosystems of the MH zone. However, at the upper elevation limit the zone features a variety of non-forested communities that were recently classified by Brett *et al.* (2001); and at the lower elevation limit it may feature a marginal occurrence of forested communities that were classified into the Tsuga heterophylla – Rhytidiadelphus loreus, Thuja plicata – Tiarella trifoliata, and Pinus contorta – Sphagnum orders (Klinka *et al.* (1996). The Tsuga mertensiana order is well segregated from the other seven coastal orders by the high presence and cover of *Abies amabilis, Chamaecyparis nootkatensis, Rhytidiopsis robusta, Rubus pedatus, Tsuga mertensiana, Vaccinium membranaceum*, and *V. ovalifolium*. However, all of the above except for *Tsuga mertensiana* and *Vaccinium membranaceum* may also occur in montane communities of the Tsuga heterophylla – Rhytidiadelphus loreus and Thuja plicata – Tiarella trifoliata orders (Klinka *et al.* 1996).

Unlike Krajina's (1969) original order Piceo (engelmannii) – Tsugo (mertensianae) – Vaccinietalia membanacei, which included both coastal (mountain hemlock-dominated) and interior (Engelmann spruce and subalpine fir-dominated) forested communities, the Tsuga mertensiana order represents only the coastal mountain hemlock, Pacific silver fir, and/or Alaska yellow-cedar-dominated communities that have developed within maritime subalpine boreal climates. The Tsuga mertensiana order characterizes and delineates the MH zone, which is the core distribution area of mountain hemlock. Subalpine mountain hemlock communities occur above those of the Tsuga heterophylla – Rhytidiadelphus order, and occur on the Coastal Mountains along the entire BC coast, and extend north through southeastern Alaska (Viereck *et al.* 1992) and south into Washington and Oregon (Franklin & Dyrness 1973).

Mountain hemlock nearly always constitutes a substantial portion of the tree layer, with Pacific silver fir (except on the Queen Charlotte Islands) and Alaska yellow-cedar being the only major associates. In the submaritime portion of the MH zone, subalpine fir and Engelmann spruce are often found on disturbed, drier, and warmer sites. Pacific silver fir regenerates abundantly in the understory, while mountain hemlock regeneration usually becomes established after canopy gaps have developed in later successional stages. In addition to advance regeneration, the predominance of ericaceous shrubs and bryophytes are characteristic features of the understory. The associated soils are generally shallow to moderately deep, coarse-skeletal, Ferro-Humic Podzols with strongly mycelial Mor humus forms. Regardless of mineral soil depth, roots of forest trees are largely confined to very acid and thick forest floors (often >50 cm).

All 452 sample plots were classified into a hierarchy of vegetation units that included 4 suborders, 8 alliances, 12 associations, and 10 subassociations (Table 3.3.6). This hierarchy is nearly identical to that developed by Klinka *et al.* (1996). These units were delineated according to the floristic differences (diagnostic combinations of species) summarized in Table 3.3.7. The differentiated summary table provides an easy overview of floristic affinities and potential differential species (Table 3.3.8).

Table 3.3.6. Synopsis of forested vegetation units delineated in the MH zone, indicating the levels of generalization and relationships among the units. Numerical codes indicate the position of a unit in the hierarchy; the same codes are used in the diagnostic and summary vegetation tables. An asterisk (*) indicates insufficient sampled units (<10 plots); two asterisks indicate a newly framed plant association; *n.n.* (nomen novum) is added if the name has been changed.

Code	Suborder
	Alliance
	Association
	Subassociation

100	**Tsuga mertensiana – Coptis aspleniifolia**
110	Tsuga mertensiana – Cassiope stelleriana*
111	**Tsuga mertensiana – Cassiope stelleriana* Klinka *et al.* 1996 (7 plots)**
120	Tsuga mertensiana – Coptis aspleniifolia
121	**Tsuga mertensiana – Vaccinium ovalifolium Klinka *et al.* 1996**
121a	Tsuga mertensiana – Vaccinium ovalifolium: typic (26 plots)
121b	Tsuga mertensiana – Vaccinium ovalifolium: Calamagrostis nutkaensis* (8 plots)
121c	Tsuga mertensiana – Vaccinium ovalifolium: Caltha leptosepala (12 plots)
122	**Tsuga mertensiana – Fauria crista-galli ** (13 plots)**
130	Tsuga mertensiana – Empetrum nigrum
131	**Tsuga mertensiana – Empetrum nigrum ** (15 plots)**
200	**Tsuga mertensiana – Vaccinium membranaceum**
210	Tsuga mertensiana – Phyllodoce
211	**Chamaecyparis – Phyllodoce *n.n.* Klinka *et al.* 1996 (32 plots)**
212	**Abies lasiocarpa – Phyllodoce** (22 plots)**
220	Tsuga mertensiana – Vaccinium membranaceum
221	**Tsuga mertensiana – Cladothamnus pyroliflorus Klinka *et al.* 1996 (24 plots)**
222	**Tsuga mertensiana – Vaccinium membranaceum Klinka *et al.* 1996**
222a	Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis (50 plos)
222b	Tsuga mertensiana – Vaccinium membranaceum: Pleurozium schreberi (92 plots)
222c	Tsuga mertensiana – Vaccinium membranaceum: Streptopus roseus (14 plots)
300	**Tsuga mertensiana – Streptopus roseus**
310	Tsuga mertensiana – Streptopus roseus
311	**Abies amabilis – Streptopus roseus *n.n.* Klinka *et al.* 1996**
311a	Abies amabilis – Streptopus roseus: Rhytidiopsis robusta (45 plots)
311b	Abies amabilis – Streptopus roseus: Tiarella trifoliata (19 plots)
312	**Abies lasiocarpa – Valeriana sitchensis Klinka *et al.* 1996**
312a	Abies lasiocarpa – Valeriana sitchensis: Vaccinium membranaceum (20 plots)
312b	Abies lasiocarpa – Valeriana sitchensis: Athyrium filix-femina (35 plots)
320	Tsuga mertensiana – Lysichiton americanum** (14 plots)
321	**Tsuga mertensiana – Lysichiton americanum** (14 plots)**
400	**Tsuga mertensiana – Sphagnum***
410	Tsuga mertensiana – Sphagnum*
411	**Tsuga mertensiana – Sphagnum** (4 plots)**

Table 3.3.7. Diagnostic combinations of species for forested vegetation units distinguished in the MH zone.

Vegetation unit	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots	7	26	8	12	13	15	32	22	24	50	92	14	45	19	20	35	14	4

Vegetation unit and species	Diagnostic value[1]	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
100 Tsuga mertensiana – Coptis aspleniifolia suborder																			
Blechnum spicant	(d)	IV 3	IV 2	V 4	V 5	V 4	III 2	I h		II +	II +	I h	II 4	III 3	III 4		I t	II 3	II 2
Chamaecyparis nootkatensis	(dd)	IV 6	IV 7	IV 6	V 7	V 7	V 7	V 6	I 1	IV 6	IV 6	I 3	III 4	II 4	II 4		I 3	II 6	III 3
Coptis aspleniifolia	(d)	V 3	V 3	V 4	V 4	IV 4	III 4			I +	I h	II 2	I 2	I 4			I +	II 4	II 3
Hylocomium splendens	(dd)	IV 5	V 6	IV 4	V 6	IV 6	V 7	I +	I +	I 4	I 4	II 4	I 2	I 3	I 4	I 4	I +	II 4	
Rhytidiadelphus loreus	(d)	V 6	V 7	V 7	V 7	V 7	V 7	I 2		III 5	III 5	II 4	IV 4	IV 5	III 5	II 4	II 4	IV 4	II 2
110/111 Tsuga mertensiana – Cassiope stelleriana alliance and association																			
Cassiope stelleriana	(d)	IV 6	I 1	II 2	I 3	I 2				I 2				I h		I h	I 3		
Cladina rangiferina	(ic)	III 2			II 1		II 3	II 3	I 3	II 4	I h	I +	I +						II h
Luetkea pectinata	(d)	III 4		II 1		I 2	I h	III 3	IV 5	I 3		I +		I +	I +	I 1	I 2		II 2
120 Tsuga mertensiana – Coptis aspleniifolia alliance																			
Streptopus roseus	(d)	II 1	IV 3	IV 4	IV 4	IV 4	I h	I +	I +	I +	I h	I +	IV 2	V 5	V 5	IV 5	V 6	V 4	II +
Tsuga heterophylla	(d)	II 3	V 7	V 6	V 5	IV 5	II 4	I h		III 3	IV 5	III 5	III 5	IV 6	III 5	II 4	II 4	IV 4	III 4
121 Tsuga mertensiana – Vaccinium ovalifolium association																			
Huperzia selago	(d)	I h	IV 2	IV 1	III 2						I +	I +		I h					
Listera cordata	(d)	II 2	V 3	V 3	V 3	II 2	II 2	I h	I h	I h	I +	I +	II +	II 1	II 2	III 1	II 1	II 1	III 1
Plagiothecium undulatum	(d)	III 3	IV 2	IV 3	III 3	I 2	I h	I t		I +	I +	I h	I +	I +	I 1	I +		I h	
Rhizomnium glabrescens	(ic)	I h	IV 4	III 4	III 3	II 3	I h	I h			I 1	I +		II 4	II 3	II 3	IV 6	IV 6	
Scapania bolanderi	(d)	II 5	V 6	V 4	IV 5	I +	I +			I 2	I +	I +	I +	I h	II +	I +	I +		
Vaccinium parvifolium	(d)	I 2	IV 3	IV 4	III 5	I 1				I +	I +	I 2	I h					I h	II 2
121a Tsuga mertensiana – Vaccinium ovalifolium: typic subassociation																			
Rhytidiopsis robusta	(dd)	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	IV 6	V 7	IV 7	IV 6	V 7	V 5	III 5	III 4	II 2	
Scapania bolanderi	(dd)	II 5	V 6	V 4	IV 5	I +	I +			I 2	I +	I +	I +	I h	II +	I +	I +	I +	
121b Tsuga mertensiana – Vaccinium ovalifolium: Calamagrostis nutkaensis subassociation																			
Calamagrostis nutkaensis	(d)	I 3	II 4	IV 6	II 3														
Dicranum scoparium	(d)	II 4	I 1	IV 3		I 2	I +	II 5	I 3	II 5	I 2	I 3	I 3	I 4	I 2				
Tiarella trifoliata	(d)	II +	II +	IV 3	II 1	I h		I +		I h	I h	I h	II 2	III 4	V 5	IV 4	V 5	IV 4	II +
121c Tsuga mertensiana – Vaccinium ovalifolium: Caltha leptosepala subassociation																			
Abies amabilis	(d)	III 4	I +	I 3	III 4	V 6	II 1	V 6	IV 6	V 7	V 7	V 7	IV 6	V 7	V 7	III 6	III 6	V 5	III 4
Caltha leptosepala	(d)	I +	II 1	II 1	V 6	I 2	I +										I 1	II 3	
Gaultheria shallon	(d)		I +	II 5	IV 6	I h	I 4			I 2	I +		I 4						
Linnaea borealis	(d)		I h	I h	III 4	II +	II 2	I +		I +	I h	I h	I +					I h	
Lysichiton americanum	(d)		I h	I h	III 3	II +	I h				I h		I h		II 1		I +	V 6	II 1
Maianthemum dilatatum	(d)		I +		III 2					I h	I h		I +						
Mylia taylorii	(d)		I h		III 2	I h	I +	I +				I h						I h	
Sphagnum girgensohnii	(d)	I 3	II 3	III 5	V 7	V 5	III 4					I h	I 4	I +	III 4	I +	I 4	III 5	III 7
Thuja plicata	(d)	III 4	II 3	I 5	IV 6		I 4			I h	I h		I 4	I 2				I h	

Species presence[2] and species significance[3]

Vegetation unit		111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots		7	26	8	12	13	15	32	22	24	50	92	14	45	19	20	35	14	4
Vegetation unit and species	Diagnostic value[1]							Species presence[2] and species significance[3]										
122 Tsuga mertensiana – Fauria crista-galli association																			
Abies amabilis	(d)	III 4	I +	I 3	III 4	V 6	II 1	V 6	IV 6	V 7	V 7	V 7	IV 6	V 7	V 7	III 6	III 6	V 5	III 4
Cladothamnus pyroliflorus	(d)		I h	I 1	II 4	III 6	II 5	II 5	II 4	V 7	I 1	I +	I 1	II 2	I 4	I 4	I 3	I 4	II 2
Fauria crista-galli	(d)	III 1	I +	II 3	I +	V 6	I 1				I h	I t	I 3	I 3	I h	I h	II 3	IV 5	III 5
Phyllodoce empetriformis	(ic)	II 6			II 3	III 5	V 6	V 6	V 6	IV 5	II 2	I 1	I +	I 2	I 3	I 2	I 1	II 3	III 4
Rhytidiopsis robusta	(d)	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	V 5	IV 5	IV 5	V 4	V 6	IV 6	V 5	V 5	II 2	
130/131 Tsuga mertensiana – Empetrum nigrum alliance and association																			
Cassiope mertensiana	(ic)	II 4		I 5	I 5	I 1	III 3	V 6	IV 6	II 3	I h	I h		I 2		I 2	I 2		III 3
Empetrum nigrum	(d)	II 5	I h	I h	II 1	I 2	V 7	I 2		I 2		I h		I h					
Kalmia microphylla	(d)				I h		III 3									I t			II 3
Phyllodoce empetriformis	(d)	II 6			II 3	III 5	V 6	V 6	V 6	IV 5	II 2	I 1	I +	I 2	I 3	I 2	I 1	II 3	III 4
Pleurozium schreberi	(dd)	III 4			I 3	II 4	IV 6	II 4	I +	III 5	I +	III 6	II 4	II 4	I 4	II 4	II 4	III 3	III 4
Vaccinium caespitosum	(ic)					II 2	III 4	I 3	I 1		I h						I +		
Vaccinium membranaceum	(ic)				I h	II 5	III 4	V 6	V 6	V 6	IV 6	IV 4	III 5	III 5	V 6	V 4	III 3	III 4	III 4
200 Tsuga mertensiana – Vaccinium membranaceum suborder																			
Vaccinium membranaceum	(d)				I h	II 5	III 4	V 6	V 6	V 6	IV 5	IV 6	IV 4	III 5	III 5	V 6	V 4	III 3	III 4
210 Tsuga mertensiana – Phylodoce empetriformis alliance																			
Cassiope mertensiana	(d)	II 4		I 5	I 5	I 1	III3	V 6	IV 6	II 3	I h	I h		I 2		I 2	I 2		III 3
Luetkea pectinata	(d)	III 4		II 1		I 2	I h	III 3	IV 5	I 3		I +		I +	I +	I 1	I 2		II 2
Phyllodoce empetriformis	(d)	II 6			II 3	III 5	V 6	V 6	V 6	IV 5	II 2	I 1	I +	I 2	I 3	I 2	I 1	II 3	III 4
211 Chamaecyparis nootkatensis – Phylodoce empetriformis association																			
Chamaecyparis nootkatensis	(d)	IV 6	IV 7	IV 6	V 7	V 7	V 7	V 6	I 1	IV 6	IV 6	I 3	III 4	II 4	II 4		I 3	II 6	III 3
Rhytidiopsis robusta	(d)	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	IV 6	V 7	IV 7	IV 6	V 7	V 5	III 5	III 4	II 2	
212 Abies lasiocarpa – Phylodoce empetriformis association																			
Abies lasiocarpa	(d)		I 3	I 2	I 2		I 2		IV 6	I 2	I h	II 5	II 4	I 3	I 2	V 7	IV 6	III 5	II 1
Dicranum fuscescens	(d)	III 4	III 3	II 2	II 1	II 5	II 3	II 6	IV 6	III 6	II 5	III 6	III 5	III 5	III 4	III 6	IV 5	IV 3	II h
Rhododendron albiflorum	(d)							II 6	III 6	II 5	II 3	II 4	II 2	I 2	I 3	I +			II 4
220 Tsuga mertensiana – Vaccinium membranaceum alliance																			
Menziesia ferruginea	(d)		III 3	V 4	V 4	IV 4	III 3	II 4	II 4	V 5	III 4	IV 5	IV 5	IV 4	III 4	II 4	III 4	V 4	IV 5
Rubus pedatus	(d)	IV 3	III 2	V 3	V 4	V 5	II 3	III 3	II 2	V 5	IV 5	IV 5	V 4	V 6	IV 6	V 5	V 5	V 4	IV 4
Tsuga heterophylla	(d)	II 3	V 7	V 6	V 5	IV 5	II 4	I h		III 3	IV 5	III 5	III 5	IV 6	III 5	II 4	II 4	IV 4	III 4
Vaccinium ovalifolium	(dd)	III 5	IV 6	V 7	V 7	V 7	IV 7	IV 5	III 6	V 7	V 7	V 7	V 7	V 7	V 7	IV 6	V 6	V 6	V 5
221 Tsuga mertensiana – Cladothamnus pyroliflorus association																			
Cladonia bellidiflora	(d)	I +	I h		I +	I h		II 2	I 1	III 2	I +	I h	I h			I +	I h	I h	II h
Cladothamnus pyroliflorus	(d)		I h	I 1	II 4	III 6	II 5	II 5	II 4	V 7	I 1	I +	I 1	II 2	I 4	I 4	I 3	I 4	II 2
Phyllodoce empetriformis	(d)	II 6			II 3	III 5	V 6	V 6	V 6	IV 5	II 2	I 1	I +	I 2	I 3	I 2	I 1	II 3	III 4

Zonal Report

Vegetation unit		111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots		7	26	8	12	13	15	32	22	24	50	92	14	45	19	20	35	14	4

Vegetation unit and species	Diagnostic value[1]									Species presence[2] and species significance[3]									

222 Tsuga mertensiana – Vaccinium membranaceum association

222a Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis subassociation

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Chamaecyparis nootkatensis	(dd)	IV 6	IV 7	IV 6	V 7	V 7	V 7	V 6	I 1	IV 6	IV 6	I 3	III 4	II 4	II 4		I 3	II 6	III 3

222b Tsuga mertensiana – Vaccinium membranaceum: Pleurozium schreberi subassociation

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Pleurozium schreberi	(dd)	III 4			I 3	II 4	IV 6	II 4	I +	III 5	I +	III 6	II 4	II 4	I 4	II 4	II 4	III 3	III 4

222c Tsuga mertensiana – Vaccinium membranaceum: Streptopus roseus subassociation

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Streptopus roseus	(d)	II 1	IV 3	IV 4	IV 4	IV 4	I h	I +	I +	I +	I h	I +	IV 2	V 5	V 5	IV 5	V 6	V 4	II +
Veratrum viride	(d)	III 4	III 3	IV 4	V 4	IV 4	III 2	I +	II 1	II 1	I h	I h	III 2	III 2	IV 4	IV 3	V 4	V 4	IV 4

300 Tsuga mertensiana – Streptopus roseus suborder

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Streptopus roseus	(dd)	II 1	IV 3	IV 4	IV 4	IV 4	I h	I +	I +	I +	I h	I +	IV 2	V 5	V 5	IV 5	V 6	V 4	II +
Tiarella trifoliata	(d)	II +	II +	IV 3	II 1	I h		I +		I h	I h	I h	II 2	III 4	V 5	IV 4	V 5	IV 4	II +

310 Tsuga mertensiana – Streptopus roseus alliance

311 Abies amabilis – Streptopus roseus association

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Abies amabilis	(d)	III 4	I +	I 3	III 4	V 6	II 1	V 6	IV 6	V 7	V 7	V 7	IV 6	V 7	V 7	III 6	III 6	V 5	III 4
Blechnum spicant	(d)	IV 3	IV 2	V 4	V 5	V 4	III 2	I h		II +	II +	I h	II 4	III 3	III 4		I t	II 3	II 2
Rhytidiadelphus loreus	(d)	V 6	V 7	V 7	V 7	V 7	V 7	I 2		III 5	III 5	II 4	IV 4	IV 5	III 5	II 4	II 4	IV 4	II 2
Rhytidiopsis robusta	(d)	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	IV 6	V 7	IV 7	IV 6	V 7	V 5	III 5	III 4	II 2	
Tsuga heterophylla	(d)	II 3	V 7	V 6	V 5	IV 5	II 4	I h		III 3	IV 5	III 5	III 5	IV 6	III 5	II 4	II 4	IV 4	III 4

311a Abies amabilis – Streptopus roseus: Rhytidiopsis robusta subassociation

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Rhytidiopsis robusta	(dd)	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	IV 6	V 7	IV 7	IV 6	V 7	V 5	III 5	III 4	II 2	

311b Abies amabilis – Streptopus roseus: Tiarella trifoliata subassociation

Species	Dv	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Athyrium filix-femina	(d)		I h	II +	I h						I t		II 1		IV 5	II 1	IV 6	IV 6	II +
Clintonia uniflora	(d)					II 1	I h	I h		I 2	II 2	I 3	II 3	II 3	IV 3	I +	I +		II 2
Gymnocarpium dryopteris	(d)		I +	II 3		I h			I h		I t	I h	II 1	II 2	V 5	IV 4	V 6	IV 4	
Oplopanax horridus	(d)										I t	I 2	I h	III 5	I +	II 5	I +		
Rhizomnium nudum	(d)		I 1		I 2			I +		I h	I 2	I +	II 3	IV 5	II 4	II 4	I 4		
Rubus spectabilis	(d)		I h	I 1	II 2					I t	I h		I 2	I 3	IV 4	I 1	III 4	IV 4	
Sphagnum girgensohnii	(d)	I 3	II 3	III 5	V 7	V 5	III 4				I h	I 4	I +	III 4	I +		I 4	III 5	III 7
Streptopus amplexifolius	(d)		I h	II 2	II 1	I h				I t	I h		II +	II +	IV 2	I +	I +	II 2	II 2
Tiarella trifoliata	(d)	II +	II +	IV 3	II 1	I h		I +		I h	I h	I h	II 2	III 4	V 5	IV 4	V 5	IV 4	II +
Valeriana sitchensis	(d)		I h	I +			I h	I h	I +	I +		I +	II h	I +	III 3	V 5	V 5	III 4	

Vegetation unit		111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots		7	26	8	12	13	15	32	22	24	50	92	14	45	19	20	35	14	4
Vegetation unit and species	Diagnostic value[1]									Species presence[2] and species significance[3]									
312 Abies lasiocarpa – Valeriana sitchensis association																			
Abies lasiocarpa	(d)			I 3	I 2	I 2		I 2	IV 6	I 2	I h	II 5	II 4	I 3	I 2	V 7	IV 6	III 5	II 1
Barbilophozia lycopodioides	(d)					I h		I +	I +	I 2		II 2	I +	I h	I 1	III 3	III 4	II +	II 3
Gymnocarpium dryopteris	(d)		I +	II 3		I h				I h			I t	I h	II 1	V 5	IV 4	V 6	IV 4
Valeriana sitchensis	(d)		I h	I +			I h	I h	I +	I +		I +	II h	I +	III 3	V 5	V 5	III 4	
312a Abies lasiocarpa – Valeriana sitchensis: Vaccinium membranaceum subassociation																			
Vaccinium membranaceum	(dd)				I h	II 5	III 4	V 6	V 6	V 6	IV 5	IV 6	IV 4	III 5	III 5	V 6	V 4	III 3	III 4
312b Abies lasiocarpa – Valeriana sitchensis: Athyrium filix-femina subassociation																			
Athyrium filix-femina	(d)		I h	II +	I h							I t		II 1	IV 5	II 1	IV 6	IV 6	II +
Rhizomnium glabrescens	(d)	I h	IV 4	III 4	III 3	II 3	I h	I h			I 1	I +		II 4	II 3	II 3	IV 6	IV 6	
Rubus spectabilis	(d)		I h	I 1	II 2					I t	I h	I 2		I 3	IV 4	I 1	III 4	IV 4	
Viola glabella	(d)	I h			I h	I h						I h		I h	I 3	I h	IV 4	III 2	II h
320/321 Tsuga mertensiana – Lysichiton americanum alliance and association																			
Cinna latifolia	(ic)													I h		I h	II 2	III 3	
Equisetum arvense	(ic)													I 1	I h	I h	II 3	III 2	II 1
Fauria crista-galli	(d)	III 1	I +	II 3	I +	V 6	I 1		I h	I t			I 3	I 3	I h	I h	II 3	IV 5	III 5
Lysichiton americanum	(d)		I h	I h	III 3	II +	I h		I h					I h	II 1		I +	V 6	II 1
Mitella pentandra	(ic)				I h			I h			I h		I h	I h	I +	I +	II 2	III 2	II +
Parnassia fimbriata	(ic)				I h			I h			I h		I h		I +	I h	II 2	III 2	
Pellia neesiana	(ic)	I h	III 3	IV 4	I 1	I 2	I h				I h			I 1	I 4	I h	II 3	III 4	
Pleurozium schreberi	(ic)	III 4			I 3	II 4	IV 6	II 4	I +	III 5	I +	III 6	II 4	II 4	I 4	II 4	II 4	III 3	III 4
Rhytidiadelphus squarrosus	(ic)							I +	I h		I t			I 3	II 4	I h	II 4	III 4	
Sanguisorba canadensis	(ic)										I h					I h	II 2	III 2	
Sphagnum girgensohnii	(ic)	I 3	II 3	III 5	V 7	V 5	III 4					I h		I 4	I +	III 4	I +	I 4	III 5
400/410/411 Tsuga mertensiana – Sphagnum suborder, alliance, and association																			
Carex gynocrates	(d)																		III 5
Eriophorum angustifolium	(dd)				I +	I +	I h				I h							II 3	III 6
Lycopodium annotinum	(d)			I 1								I h			I +	I +			III 2
Sphagnum girgensohnii	(dd)	I 3	II 3	III 5	V 7	V 5	III 4					I h		I 4	I +	III 4	I +	I 4	III 7

1   Species diagnostic values: d = differential, dd = dominant differential, ic = important companion (Pojar *et al.*1987)

2   Species presence classes (the percentage of plots in which the species occurs): I = 1-20%, II = 21-40%, III = 41-60%, IV = 61-80%, V = 81-100%

3   Species significance classes and the corresponding mid-point and range (in parentheses) of cover: t = 0.005 (0.001-0.009), h = 0.05 (0.01 - 0.09), + = 0.2 (0.1-0.3), 1 = 0.7 (0.4-1.0), 2 = 1.6 (1.1-2.1), 3 = 3.6 (2.2-5.0), 4 = 7.5 (5.1-10.0), 5 = 15 (10.1-20.0), 6 = 26.5 (20.1-33.0), 7 = 41.5 (33.1-50.0), 8 = 60 (50.1-70.0), 9 = 85 (70.1-100).

Table 3.3.8. Differentiated (by descending order of presence from left to right) summary vegetation table for forested vegetation units dist inguished in the MH zone. Only species present in ≥40% of the plots of at least one unit (presence class ≥ III) are included. Numerical codes for vegetation units as in Table 3.3.6.

Vegetation unit	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots	7	26	8	12	13	26	8	12	13	15	92	14	45	19	20	35	14	4
Number of plant species	57	90	80	121	88	90	80	121	88	97	181	102	161	149	141	196	112	76
Species								Species presence and species significance[1]										
Cassiope stelleriana	IV 6	I 1	II 2	I 3	I 2			I 2					I h		I h	I 3		
Cladina rangiferina	III 2			II 1		II 3	II 3	I 3	II 4	I h	I +	I +						II h
Thuja plicata	III 4	II 3	I 5	IV 6		I 4			I h	I h		I 4	I 2				I h	
Luetkea pectinata	III 4		II 1		I 2	I h	III 3	IV 5	I 3		I +		I +	I +	I 1	I 2		II 2
Fauria crista-galli	III 1	I +	II 3	I +	V 6	I 1				I h	I t	I 3	I 3	I h	I h	II 3	IV 5	III 5
Plagiothecium undulatum	III 3	IV 2	IV 3	III 3	I 2	I h	I t			I +	I h	I +	I +	I +	I 1	I +		I h
Coptis aspleniifolia	V 3	V 3	V 4	V 4	IV 4	III 4				I +	I h	II 2	I 2	I 4		I +	II 4	II 3
Hylocomium splendens	IV 5	V 6	IV 4	V 6	IV 6	V 7	I +	I +	I 4	I 4	II 4	I 2	I 3	I 4	I 4	I +	II 4	
Pleurozium schreberi	III 4			I 3	II 4	IV 6	II 4	I +	III 5	I +	III 6	II 4	II 4	I 4	II 4	II 4	III 3	III 4
Blechnum spicant	IV 3	IV 2	V 4	V 5	V 4	III 2	I h		II +	II +	I h	II 4	III 3	III 4		I t	II 3	II 2
Chamaecyparis nootkatensis	IV 6	IV 7	IV 6	V 7	V 7	V 7	V 6	I 1	IV 6	IV 6	I 3	III 4	II 4	II 4		I 3	II 6	III 3
Cornus canadensis	III 3	III 1	V 3	V 5	IV 4	IV 4	I 1		III 3	II 2	II 3	III 5	II 3	III 3	II 2	I 1	IV 3	III +
Dicranum fuscescens	III 4	III 3	II 2	II 1	II 5	II 3	II 6	IV 6	III 6	II 5	III 6	III 5	III 5	III 4	III 6	IV 5	III 3	II h
Rhytidiadelphus loreus	V 6	V 7	V 7	V 7	V 7	V 7	I 2		III 5	III 5	II 4	IV 4	IV 5	III 5	II 4	II 4	IV 4	II 2
Rhytidiopsis robusta	III 4	III 6	II 4	I 2	V 5	IV 5	V 5	II 3	IV 6	V 7	IV 7	IV 6	V 7	V 5	III 5	III 4	II 2	
Veratrum viride	III 4	III 3	IV 4	V 4	IV 4	III 2	I +	II 1	II 1	I h	I h	III 2	III 2	IV 4	IV 3	V 4	V 4	IV 4
Abies amabilis	III 4	I +	I 3	III 4	V 6	II 1	V 6	IV 6	V 7	V 7	V 7	IV 6	V 7	V 7	III 6	III 6	V 5	III 4
Rubus pedatus	IV 3	III 2	V 3	V 4	V 5	II 3	III 3	III 2	V 5	IV 5	IV 5	V 4	V 6	IV 6	V 5	V 5	V 4	IV 4
Tsuga mertensiana	V 7	V 7	V 7	V 7	V 7	V 6	V 7	V 7	V 7	V 7	V 7	V 7	V 7	V 7	V 6	V 6	V 6	V 5
Vaccinium ovalifolium	III 5	IV 6	V 7	V 7	V 7	IV 7	IV 5	III 6	V 7	V 7	V 7	V 7	V 7	V 7	IV 6	V 6	V 6	V 5
Listera caurina		III 2	II +	III +	I +	I h	I h		I h	II 1	I h	I h	II +	I 1	I +			
Lycopodium clavatum	I h	II 2	I h	IV 3	I +	I +			I t	I h	I h	I +	I h	I h				
Moneses uniflora	I h	III +	III 1	I h		I h	I h				I h		I h					
Picea sitchensis	I 2	IV 5	IV 5		I +						I h		I +			I +	II 3	II 1
Huperzia selago	I h	IV 2	IV 1	III 2								I +	I +		I h			
Pellia neesiana	I h	III 3	IV 4	I 1	I 2	I h				I h			I 1	I 4	I h	II 3	III 4	
Scapania bolanderi	II 5	V 6	V 4	IV 5	I +	I +			I 2	I +	I +	I +	I h	II +	I +	I +	I +	
Vaccinium parvifolium	I 2	IV 3	IV 4	III 5	I 1					I +	I +	I 2	I h				I h	II 2
Listera cordata	II 2	V 3	V 3	V 3	II 2	II 2	I h	I h	I h	I +	I +	II +	II 1	II 2	III 1	II 1	II 1	III 1
Rhizomnium glabrescens	I h	IV 4	III 4	III 3	II 3	I h	I h			I 1	I +		II 4	II 3	II 3	IV 6	IV 6	
Streptopus roseus	II 1	IV 3	IV 4	IV 4	IV 4	I h	I +	I +	I +	I h	I +	IV 2	V 5	V 5	IV 5	V 6	V 4	II +
Tsuga heterophylla	II 3	V 7	V 6	V 5	IV 5	II 4	I h		III 3	IV 5	III 5	III 5	IV 6	III 5	II 4	II 4	IV 4	III 4
Menziesia ferruginea		III 3	V 4	V 4	IV 4	III 3	II 4	II 4	V 5	III 4	IV 5	IV 5	IV 4	III 4	II 4	III 4	V 4	IV 5
Calamagrostis nutkaensis	I 3	II 4	IV 6	II 3														
Dicranum scoparium	II 4	I 1	IV 3		I 2	I +	II 5	I 3	II 5	I 2	I 3	I 3	I 4	I 2				
Tiarella trifoliata	II +	II +	IV 3	II 1	I h		I +		I h	I h	I h	II 2	III 4	V 5	IV 4	V 5	IV 4	II +
Sphagnum girgensohnii	I 3	II 3	III 5	V 7	V 5	III 4					I h	I 4	I +	III 4	I +	I 4	III 5	III 7
Dicranum majus		II 3		III 3	I h				I 1									
Gaultheria shallon		I +	II 5	IV 6	I h	I 4			I 2	I +		I 4						

Vegetation unit	111	121a	121b	121c	122	131	211	212	221	222a	222b	222c	311a	311b	312a	312b	321	411
Number of plots	7	26	8	12	13	26	8	12	13	15	92	14	45	19	20	35	14	4
Number of plant species	57	90	80	121	88	90	80	121	88	97	181	102	161	149	141	196	112	76

Species							Species presence and species significance[1]											
Linnaea borealis		I h	I h	III 4	II +	II 2	I +		I +	I h	I h	I +					I h	
Maianthemum dilatatum		I +		III 2						I h	I h	I +						
Mylia taylorii		I h		III 2	I h	I +	I +				I h						I h	II 3
Caltha leptosepala	I +	II 1	II 1	V 6	I 2	I +					I h			II 1		I 1	V 6	II 3
Lysichiton americanum		I h	I h	III 3	II +	I h				I h			I h	II 1		I +	V 6	II 1
Cladothamnus pyroliflorus		I h	I 1	II 4	III 6	II 5	II 5	II 4	V 7	I 1	I +	I 1	II 2	I 4	I 4	I 3	I 4	II 2
Phyllodoce empetriformis	II 6			II 3	III 5	V 6	V 6	V 6	IV 5	II 2	I 1	I +	I 2	I 3	I 2	I 1	II 3	III 4
Empetrum nigrum	II 5	I h	I h	II 1	I 2	V 7	I 2		I 2		I h		I h					
Kalmia microphylla					I h	III 3										I t		II 3
Vaccinium caespitosum					II 2	III 4	I 3	I 1		I h						I +		
Cassiope mertensiana	II 4		I 5	I 5	I 1	III 3	V 6	IV 6	II 3	I h	I h		I 2		I 2	I 2		III 3
Vaccinium membranaceum				I h	II 5	III 4	V 6	V 6	V 6	IV 5	IV 6	IV 4	III 5	III 5	V 6	V 4	III 3	III 4
Vaccinium deliciosum					I 2	I h	III 5	II 4	I 1	I 1			I h		I 4			
Sorbus sitchensis			I 1	I +	I 2	I h	III 2	II 3	III 3	I +	II 3	III 3	II 2	III 2	II 2	III 2	I +	III +
Barbilophozia floerkei					II 4	I +	III 4	III 3	III 4	I 2	III 5	III 4	I 2	I 1	III 5	II 4	III 3	III 4
Rhododendron albiflorum							II 6	III 6	II 5	II 3	II 4	II 2	I 2	I 3		I +		II 4
Abies lasiocarpa			I 3	I 2	I 2		I 2	IV 6	I 2	I h	II 5	II 4	I 3	I 2	V 7	IV 6	III 5	II 1
Cladonia bellidiflora	I +	I h		I +	I h			II 2	I 1	III 2	I +	I h	I h		I +	I h	I h	II h
Orthilia secunda				II +	I +	I h	I t	II 3	I h	III 2	II 2		II 2	II 2	II 2	I +	II +	
Clintonia uniflora					II 1	I h	I h		I 2	II 2	II 3	II 3	II 3	IV 3	I +	I +		II 2
Oplopanax horridus										I t	I 2	I h	III 5	I +	II 5	I +		
Rhizomnium nudum		I 1		I 2			I +			I h	I 2	I +	II 3	IV 5	II 4	II 4	I 4	
Streptopus amplexifolius		I h	II 2	II 1	I h				I t	I h		II +	II +	IV 2	I +	I +	II 2	II 2
Athyrium filix-femina		I h	II +	I h						I t		I 2	II 1	IV 5	II 1	IV 6	IV 6	II +
Rubus spectabilis		I h	I 1	II 2					I t	I h		I 2	II 3	IV 4	I 1	III 4	IV 4	
Gymnocarpium dryopteris		I +	II 3		I h		I h			I t	I h	II 1	II 2	V 5	IV 4	V 6	IV 4	
Valeriana sitchensis		I h	I +			I h	I h	I +	I +		I +	II h	I +	III 3	V 5	V 5	III 4	
Barbilophozia lycopodioides					I h		I +	I +	I 2		II 2	I +	I h	I 1	III 3	III 4	II +	II 3
Mitella pentandra			I h				I h			I h			I h	I +	I +	II 2	III 2	II +
Rhytidiadelphus squarrosus									I +	I h		I t		I 3	II 4	II 4	III 4	
Parnassia fimbriata				I h			I h			I h		I h	I +		I h	II 2	III 2	
Sanguisorba canadensis										I h					I h	II 2	III 2	
Carex gynocrates																		III 5
Lycopodium annotinum			I 1								I h				I +	I +		III 2
Eriophorum angustifolium				I +	I +	I h				I h						II 3		III 6
Leptarrhena pyrolifolia								I t		I +					I +	II 4	II +	III 3
Platanthera dilatata				II 2												I h	I h	III +
Sphagnum capillifolium		I +		I 3	I h	I 2						I +				I 1	II 5	IV 6

1   Species presence and significance classes as defined in Table 3.3.7.

The numerical and tabular analyses suggested a somewhat poor floristic differentiation as reflected by the small number of species in diagnostic combinations of species (Table 3.3.7) and, hence, a relatively high number of species present with varying frequency across all or nearly all units, *e.g., Tsuga mertensiana, Chamaecyparis nootkatensis, Abies amabilis, Dicranum fuscescens, Rhytidiopsis robusta, Rubus pedatus, Vaccinium ovalifolium, Menziesia ferruginea, Pleurozium schreberi, Cornus canadensis,* and *Rhytidiadelphus loreus* (Table 3.3.8). Some species that were included in the diagnostic combinations of species have a marginal differential value, especially at the suborder and alliance levels, *e.g., Chamaecyparis nootkatensis, Streptopus roseus*, and *Vaccinium membranaceum*. However, the differences were distinct enough to frame 4 plant suborders (Table 3.3.6).

The weak floristic differentiation, or relatively high floristic similarity, between the suborders is supported by two sets of similarity indices (Table 3.3.9). These indices suggest high affinities among 3 suborders: the Tsuga mertensiana – Vaccinium membranaceum, Tsuga mertensiana – Streptopus roseus and Tsuga mertensiana – Coptis apleniifolia suborders. However, the maritime Tsuga mertensiana – Vaccinium membranaceum suborder was more similar to the other maritime suborder, the Tsuga mertensiana – Streptopus roseus, than to the hypermaritime Tsuga mertensiana – Coptis apleniifolia suborder. The Tsuga mertensiana – Sphagnum suborder was most dissimilar to the 3 other suborders, especially according to the cover-based index.

Table 3.3.9. Matrix of floristic similarities for the four forested plant suborders delineated in the MH zone. Higher values indicate a greater number of shared species and greater floristic similarity. Codes for suborders as in Table 3.3.6.

A Sørenson (coincidence) coefficient of floristic similarity based on presence/absence

	100	200	300
200	0.549		
300	0.497	0.627	
400	0.370	0.275	0.279

B Cover index (Sørenson modified) of floristic similarity based on cover

	100	200	300
200	0.374		
300	0.448	0.502	
400	0.040	0.014	0.033

The first suborder, the Tsuga mertensiana – Coptis apleniifolia suborder, with 3 alliances, 4 associations and 3 subassociations, primarily represents forested communities from a wide range of sites in hypermaritime climates. This strong affinity to hypermaritime climates is indicated by a high frequency of subalpine boreal & cool mesothermal indicator species and a low frequency of montane boreal & cool temperate indicator species, and a low frequency of deciduous shrubs (Figures 3.3.2 and 3.3.3). Compared to the Tsuga mertensiana – Vaccinium membranaceum suborder, the soil moisture spectrum of the Tsuga mertensiana – Coptis apleniifolia suborder suggests wetter soil moisture conditions (Figure 3.3.4). The Tsuga mertensiana – Cassiope stelleriana alliance is characteristic of the Wet Hypermaritime Parkland MH subzone; the Tsuga mertensiana – Coptis apleniifolia alliance, which typifies the central concept of this suborder, represents all forested communities in the Wet Hypermaritime Forested MH subzone, and the Tsuga mertensiana – Empetrum nigrum alliance represents open-canopy, forested communities on wetter sites in the lower parkland and at the upper limit of the forested MH subzones.

The second suborder, the Tsuga mertensiana – Vaccinium membranaceum suborder, has 2 alliances, 4 associations, and 3 subassociations, and primarily represents forested communities on intermediate sites in maritime and submaritime climates. This affinity to both maritime and submaritime climates is reflected by the high frequency of deciduous shrubs (Figure 3.3.2) and montane boreal & cool temperate indicator species (Figure 3.3.3). Compared to the other suborders, this suborder includes forested communities associated with the relatively driest and poorest sites, which is reflected by a high frequency of species indicating moderately dry to fresh soil moisture conditions and poor soil nutrient conditions (Figures 3.3.4 and 3.3.5). The Tsuga mertensiana – Phyllodoce empetriformis alliance is characteristic of the Moist Maritime-Submaritime Parkland MH subzones; the Tsuga mertensiana – Vaccinium alliance, which typifies the central concept of this suborder, includes forested communities on zonal sites in maritime climates (the Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis subassociation) and submaritime climates (the Tsuga mertensiana – Vaccinium membranaceum: Pleurozium schreberi subassociation).

Figure 3.3.2. Life-form spectra of the four forested plant suborders delineated in the MH zone. Percent values denote relative frequencies; codes for the suborders as in Table 3.3.6.

Figure 3.3.3. Climatic spectra of the four forested plant suborders delineated in the MH zone. Percent values denote relative frequencies; codes for the suborders as in Table 3.3.6.

Mountain Hemlock Zone
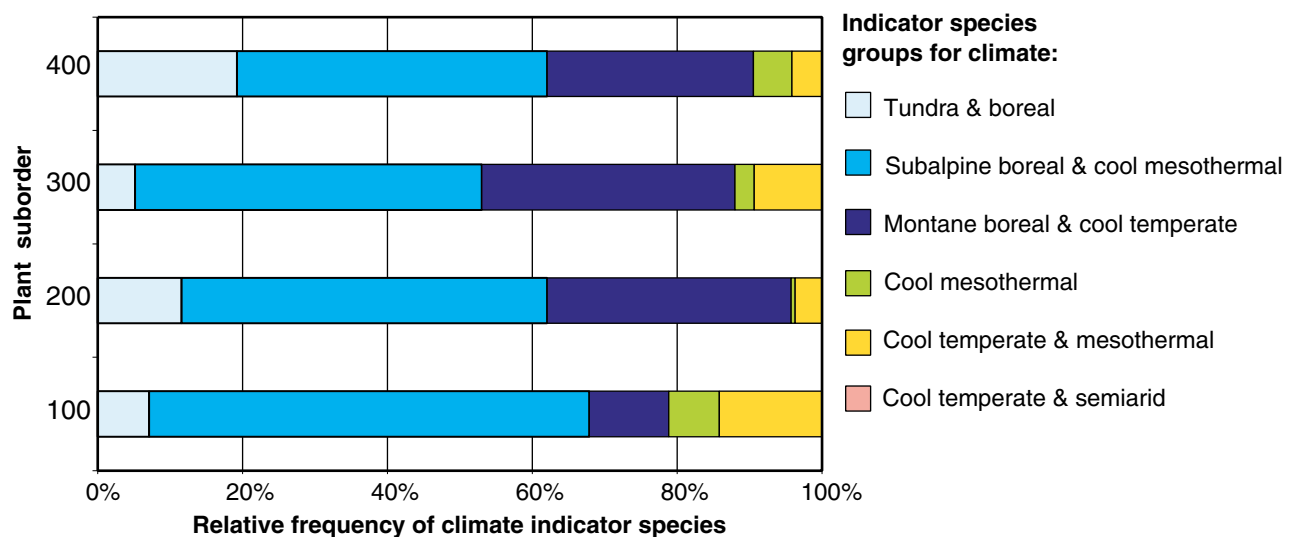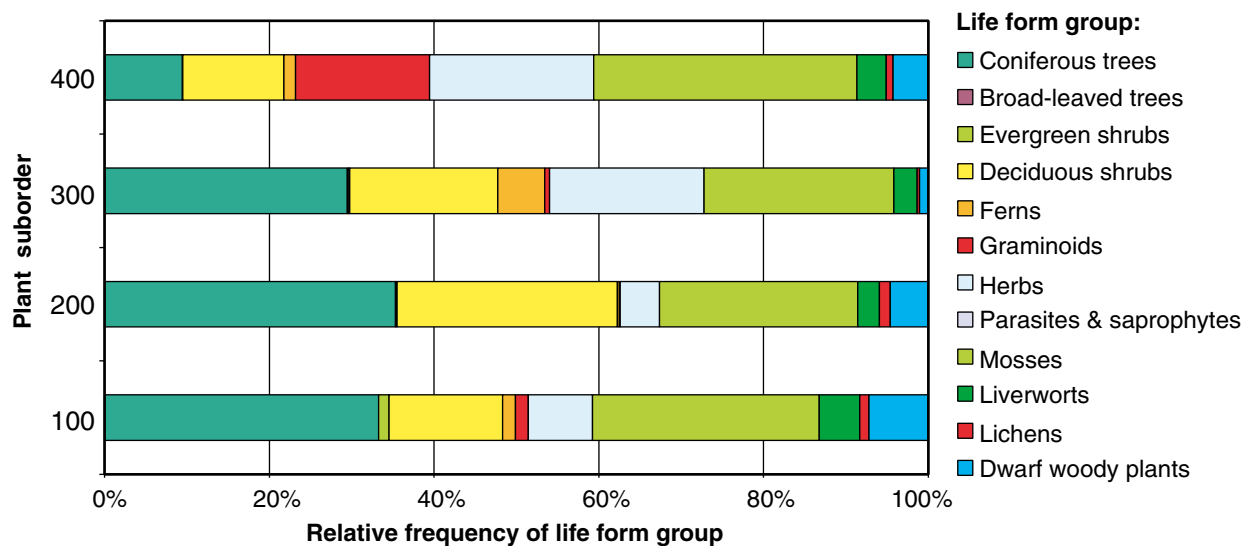
The third suborder, the Tsuga mertensiana – Streptopus roseus suborder, with 2 alliances, 3 associations, and 4 subassociations, represents forested communities on richer sites, primarily in maritime and submaritime climates. The climatic spectrum of this suborder, which is similar to that for the Tsuga mertensiana – Vaccinium membranaceum suborder, suggests affinity to maritime and submaritime climates (Figure 3.3.3); The soil moisture spectrum, which is nearly identical to that for the Tsuga mertensiana – Coptis aspleniifolia suborder, indicates moist soil conditions (Figure 3.3.4). However, compared to other suborders, a high frequency of the nitrogen-rich indicator species suggests that these communities occur on medium or richer soils (Figure 3.3.5).

The fourth suborder, the Tsuga mertensiana – Sphagnum suborder, with 1 alliance and 1 association, represents forested communities on wet and poor soils across the MH zone. These edaphic conditions are reflected by the soil moisture and nutrient spectra (Figures 3.3.4 and 3.3.5).
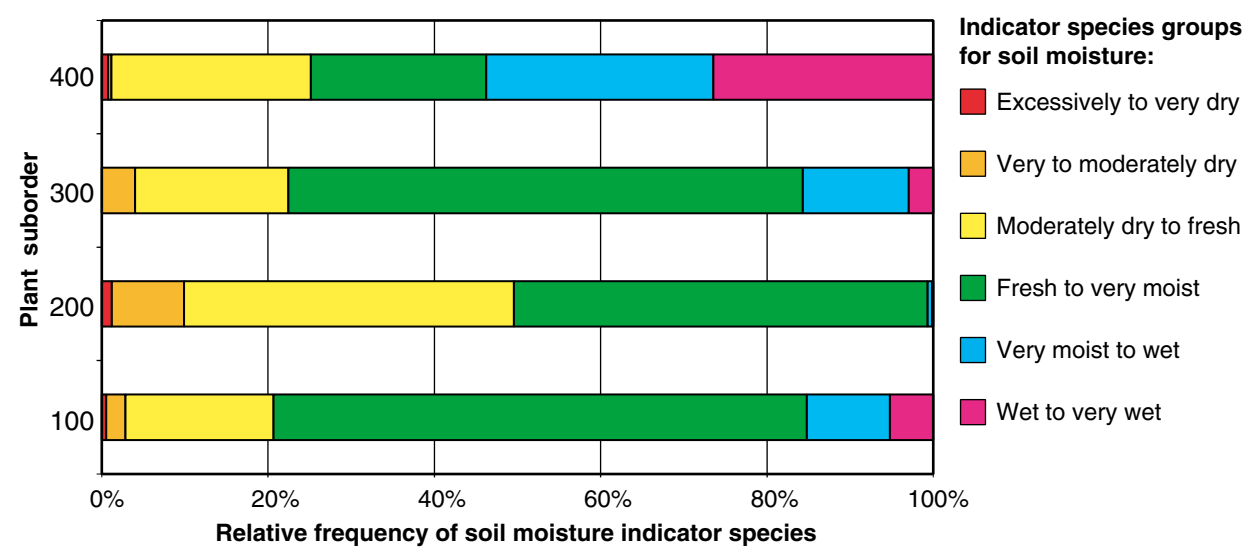
Figure 3.3.4. Soil moisture spectra of the four forested plant suborders delineated in the MH zone. Percent values denote relative frequencies; codes for the suborders as in Table 3.3.6.
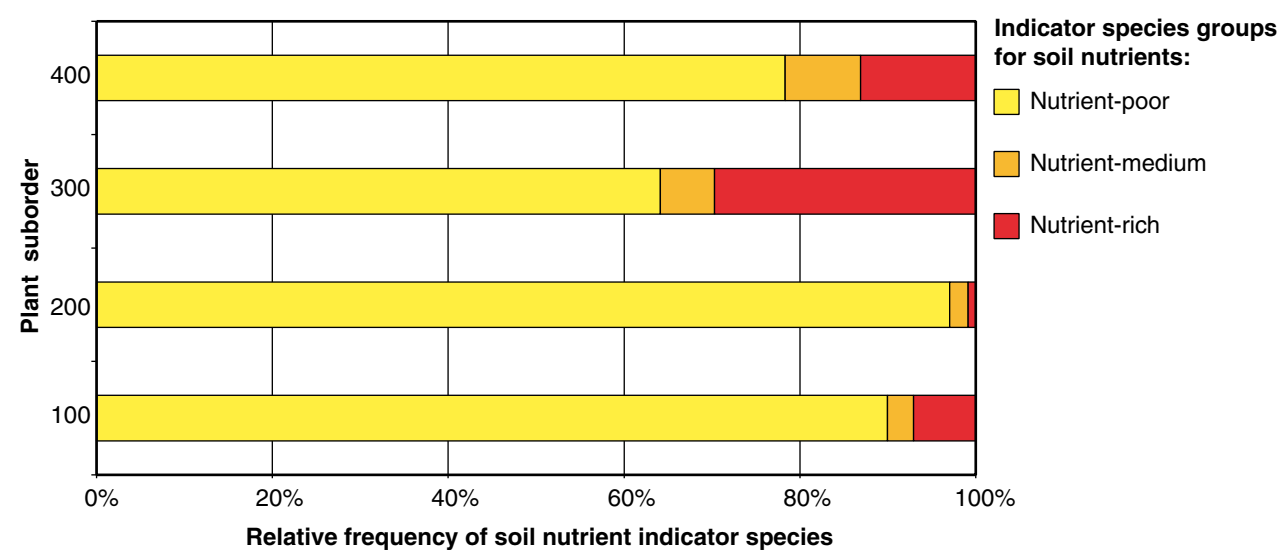
Figure 3.3.5. Soil nutrient spectra of the four forested plant suborders delineated in the MH zone. Percent values denote relative frequencies; codes for the suborders as in Table 3.3.6.

3.4 SITE CLASSIFICATION

The purpose of site classification is to organize local ecosystems into classes (groups) that are alike in the environmental characteristics that determine potential for the development of particular vegetation (plant community type - usually plant association or subassociation). Thus delineated site units represent groups of ecologically equivalent sites with similar vegetation and productivity potentials. Climate (represented by biogeoclimatic subzone or variant), soil moisture regime, soil nutrient regime, and if appropriate, additional environmental factors, are the sole differentiating characteristics used to classify ecosystems *via* sites into a hierarchy of site units, of which the site association is the principal category. Each site association has an exclusive combination of these selected site factors, which is used to identify sites (ecosystems) of that unit.

The approach to, and principles of, site classification outlined above are applicable to environmental conditions in which the environmental properties selected as differentiating characteristics are true and easily identifiable determinants of the ecosystem pattern in the landscape so that it is possible to predict the presence or development of a given plant community given certain environmental conditions. With some exceptions, such predictions are possible for forested communities because it is possible to estimate the climatic (albeit at the regional level), soil moisture, and soil nutrient conditions for a given site. These are the three principal determinants of the site quality of forested sites that account for most of the variation in ecosystem pattern in the landscape.

The site classification was derived from the vegetation classification, *i.e.*, site associations were derived from plant associations or subassociations representing plant communities in late-seral successional stages in the Mountain Hemlock zone. This choice helped to describe potential vegetation that develops on particular sites in the absence of disturbance. Each vegetation unit was characterized by its occurrence in biogeoclimatic units (subzones or variants), and its range of soil moisture and nutrient regimes. It is assumed that each unique plant community type representing late-seral vegetation will be associated with a unique type of sites (environment, habitat). To frame mutually exclusive units, each valid site association is required to be different in the expression of at least one of the properties used as differentiating characteristics from other site associations. For example, a difference in biogeoclimatic unit alone (*e.g.*, MHwh subzone *versus* MHmm variant) is sufficient for framing two site associations with the same edaphic conditions (*i.e.*, range of soil moisture and nutrient regimes). Similarly, a difference in soil moisture regime alone (*e.g.*, fresh *versus* moist) is sufficient for framing two site associations with the same climatic and soil nutrient conditions.

The development of mutually exclusive site associations presupposes a 1:1 correspondence between vegetation units and site associations: each vegetation unit is different in the expression of at least one of the properties used as differentiating characteristics from other vegetation units. This situation, however, may not always occur; instead, some vegetation units may partially or even fully overlap with other units in one or more properties selected for differentiation of site associations. For example, two (or occasionally more) vegetation units may have the same climatic and soil moisture characteristics, and both have medium soil nutrient conditions, with the former ranging from very poor to medium conditions, and the latter from medium to very rich conditions. Consequently, site identification on sites with medium soil nutrient conditions will be ambiguous, unless aided by floristic characteristics, which may not be expressed in some successional stages. There are two possible solutions to resolve this problem. First, the examination of vegetation and environmental data of the overlapping plots in both vegetation units may reveal some inconsistencies and suggest explanation for the overlap. For example, open-canopy conditions might have promoted a more vigorous development of understory vegetation in some plots on medium sites, and allocation of these plots to the latter vegetation unit. Other factors that may affect the floristic composition (and thus the overlap in environmental characteristics) are the successional stage, or differences in the cover of different ground surface materials, especially decaying wood. This situation may be resolved by allocating all plots overlapping in a particular property to one or the other vegetation unit. Second, if examining the vegetation and environmental data of the environmentally overlapping plots in two vegetation units does not reveal any inconsistencies, it is necessary to search for one or more additional environmental property(ies) that had a strong influence on the development of vegetation of the overlapping vegetation units. For example, one vegetation unit may be associated with colluvial materials

or a strongly fluctuating water table, which, when used as an additional differentiating characteristic, removes an overlap between vegetation and contributes to the exclusive differentiation of site associations.

In this report, we first present the site classification for the parkland MH subzone, and then the classification for the forested MH subzones. The classification includes a synopsis, environmental matrices, edatopic grids, topographic sequences, and the results of spectral analysis. Description of the site units, which focuses on site groups or site associations, is given in Section 3.5 DESCRIPTION OF THE SITE UNITS starting on page 65.

Parkland MH Subzones

Despite the fact that the relationship between vegetation patterns and environmental gradients in the upper subalpine and alpine non-forested communities is possibly stronger than in submontane, montane, and subalpine forested communities, it is not the regional climate but the local climate that has the strongest influence on vegetation (Archer 1963; Brooke *et al.* 1970; Franklin and Dyrness 1973; Evans 1986). The strongest gradients develop in relation to the time of snowmelt, the distance from standing or flowing water, and the time elapsed since deglaciation or disturbances, such as avalanches. Although some inference can be made from second order site properties, such as aspect, slope gradient, and slope position, it is difficult to estimate the duration of the snowpack for each type of non-forested plant community type. Therefore, it is not possible at this time to determine definite relationships of non-forested plant communities with their habitats or to reliably predict their occurrence in the landscape from a few selected environmental properties. This was the reason for delineating site groups (the highest category of the site classification) instead of site associations for non-forested vegetation units. Although more generalized, site groups will provide for a more feasible and definite site identification in the complex MH parkland landscape.

As a result, the site classification presented for the parkland MH subzones is imperfect because one cannot identify sites without the aid of vegetation. In addition, the classification is incomplete as it is applicable predominantly to the MHmm-sp subzone, specifically to the MHmmp variant, due to the lack of samples from the MHwhp subzone and MHmsp variant. Thus, the distinguished site units best represent the MHmmp variant. These difficulties notwithstanding, we were able to distinguish general environmental types that appear to describe reasonably well the habitats of both non-forested and forested ecosystems in the parkland MH subzones, as did previous researchers (Archer 1963; Brooke *et al.* 1970; Klinka *et al.* 1997; Brett *et al.* 2001).

A synopsis of the site units along with the parent vegetation units and the habitats characteristic of the units is given in Table 3.4.1. A climatic-edaphic matrix that demonstrates the relationships of site units to gradients of snow duration (after Brooke *et al.* (1970) and soil moisture is given in Figure 3.4.6. Three differentiating characteristics, (i) general classes of snow duration (snowmelt, Figure 3.4.6), (ii) actual soil moisture regimes (Figure 3.4.1), and (iii) additional environmental properties, (habitats, Figure 3.4.2) provide good differentiation of the delineated site units. Two generalized topographic sequences for gentler and steeper terrain illustrating the relationships between site units on the landscape are shown in Figure 3.4.2. The soil moisture and soil nutrient spectra offer a vegetation-inferred comparison of soil moisture and nutrient conditions of the site units (Figures 3.4.3 and 3.4.4). Since little is known about soil nutrient conditions of non-forested ecosystems at this time, the soil nutrient regime was not explicitly used as a differentiating characteristic.

Table 3.4.1. Synopsis and parent vegetation units of the site units derived from non-forested and forested vegetation units in the parkland MH subzones. Codes for parent vegetation units as in Tables 3.3.1 and 3.3.6; Hm - mountain hemlock, Ba - Pacific silver fir, Bl - subalpine fir, Yc - Alaska yellow-cedar.

	Site group or association		Parent vegetation unit
A	Rhizocarpon site group	1	Rhizocarpon geographicum plant order
B	Phlox site group	2	Phlox diffusa plant order
C	HmYc – Rhacomitrium site association		Tentative site association; not yet adequately sampled
D	HmBa – Mountain-Heather site association	211	Chamaecyparis – Phyllodoce plant association
E	HmBl – Mountain-Heather site association	212	Abies lasiocarpa – Phyllodoce plant association
F	Hm – Mountain-Heather site association	111	Tsuga mertensiana – Cassiope stelleriana plant association
G	Hm – Crowberry site association	131	Tsuga mertensiana – Empetrum nigrum plant association
H	Mountain-Heather site group	5	Cassiope – Phyllodoce plant order
I	Valerian site group	8	Valeriana sitchensis plant order
J	Sitka Alder site group	9	Alnus viridis plant order
K	Swamp Moss site group	7	Philonotis fontana plant order
L	Showy Sedge site group	6	Carex spectabilis plant order
M	Marsupella site group	3	Marsupella brevissima plant order
N	Several-Flowered Sedge site group	11	Sphagnum – Carex plant order
O	Cotton-grass site group	10	Eriophorum angustifolium plant order
P	Alpine Sedge site group	4	Carex nigricans plant order

	SD - MD	F - M	VM	W	VW

< 8 months

- **Rhizocarpon** (exposed rocks)
- **Phlox** (warm aspect, base-rich soils)
- **HmYc - Rhacomitrium** (very steep-rocky sites)
- **Hm - Mountain-Heather** (MHwh)
- **HmBa - Mountain-Heather** (MHmm)
- **HmBl - Mountain-Heather** (MHms)

- **Hm - Crowberry** (flat terrain in the lower elevation limits of the parkland MH subzones

- **Swamp Moss** (springs, seeps, stream-edges)

- **Several-Flowered Sedge** (wetlands)

between 8 and 9 months

- **Mountain-Heather** (zonal sites)
- **Sitka Alder** (avalanche tracks)
- **Valerian** (meadows)

- **Cotton-Grass** (wetlands)

> 9 months

- **Showy Sedge** (rubble fields)
- **Marsupella** (sheet-wash; late-snowmelt sites)

- **Alpine Sedge** (late-snowmelt sites)

Increasing snow duration

Figure 3.4.1. A climatic-edaphic grid showing relationships of the site groups and associations in the parkland MH subzones to gradients of snow duration and soil moisture.
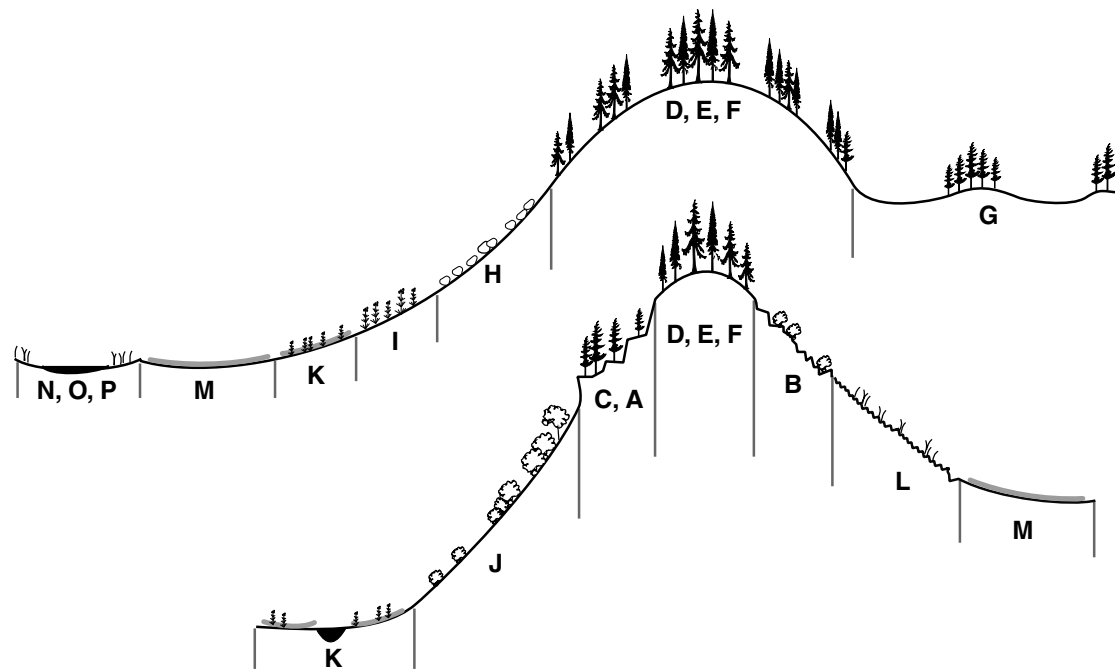
	Site association or group	Habitat
A	Lichen site group	exposed rock walls, rock bluffs, rocky ridges with early snowmelt
B	Phlox site group	warm-aspect, base-rich, exposed bedrock
C	HmYc – Rhacomitrium site association	precipitous rock bluffs with early snowmelt; more often in the lower elevational limits of the parkland
D	HmBa – Mountain-Heather site association	tree islands on ridge crests with early snowmelt in the MHmmp variant
E	HmBl – Mountain-Heather site association	tree islands on ridge crests with early snowmelt in the MHmsp variant
F	Hm – Mountain-Heather site association	tree islands on ridge crests with early snowmelt in the MHwhp subzone
G	Hm – Crowberry site association	flat terrain in the lower elevation with delayed snowmelt in the transition area between the MHmm-sp subzone and the MHmm-s subzone
H	Mountain-Heather site group	well-drained, zonal sites
I	Valerian site group	fresh to very moist, nutrient-rich, mid-slopes
J	Sitka Alder site group	fresh to very moist avalanche tracks throughout the parkland and forested subzones
K	Swamp Moss site group	seeps, springs, stream-edges
L	Showy Sedge site group	talus slopes, rubble fields, fragmental rock, moraines
M	Marsupella site group	slightly dry to moist, late-snowmelt patches and basins; also unstable sheet-wash slopes
N	Several-Flowered Sedge site group	wet to very wet sites with a very slowly moving water table and a snow duration of <8 months at the lower elevation limit of the parkland subzones and throughout the forested subzones
O	Cotton-Grass site group	wet to very wet sites with very slow or stagnant water table; wetlands in the lower elevation limits of the MHmmp subzone
P	Alpine Sedge site group	late-snowmelt basins, very moist to very wet soil moisture conditions

Figure 3.4.2. Generalized topographic sequences for gentler and steeper terrain showing the relationships between site units on the landscape of the parkland MH subzones.
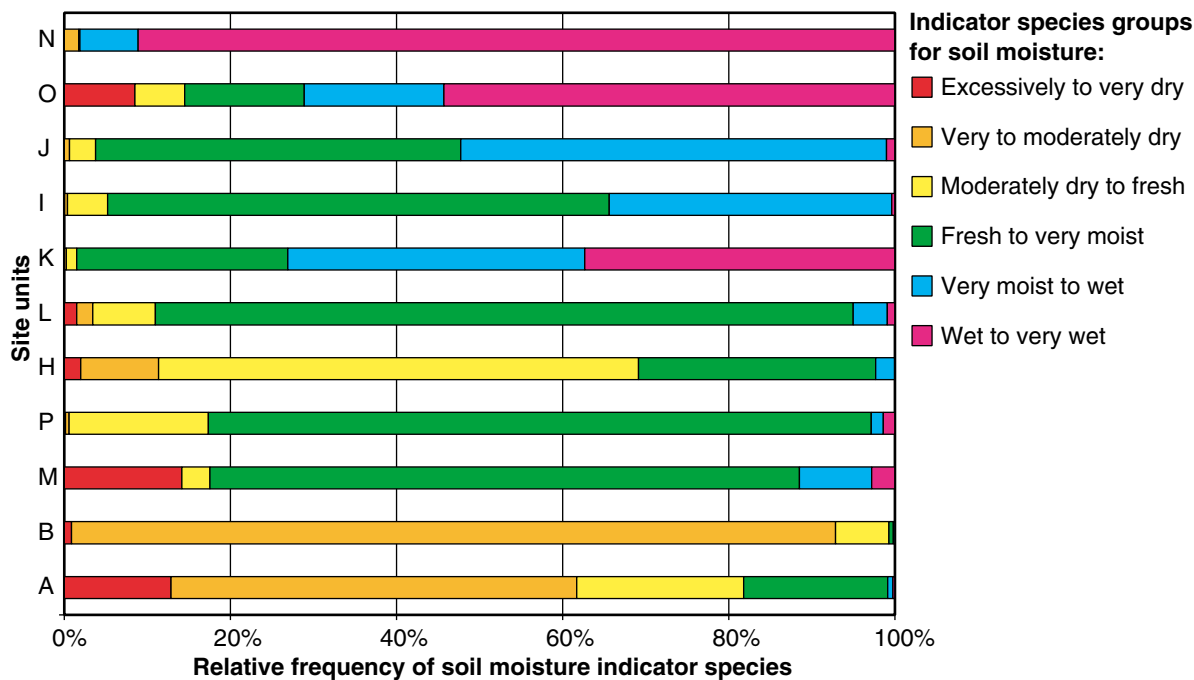
Figure 3.4.3. Soil moisture spectra for the non-forested site units in the parkland MH subzones. Percent values denote relative frequencies. Forested site groups (C,D,E,F, and G) are included in Figure 3.4.10. Codes for site units as in Table 3.4.1.
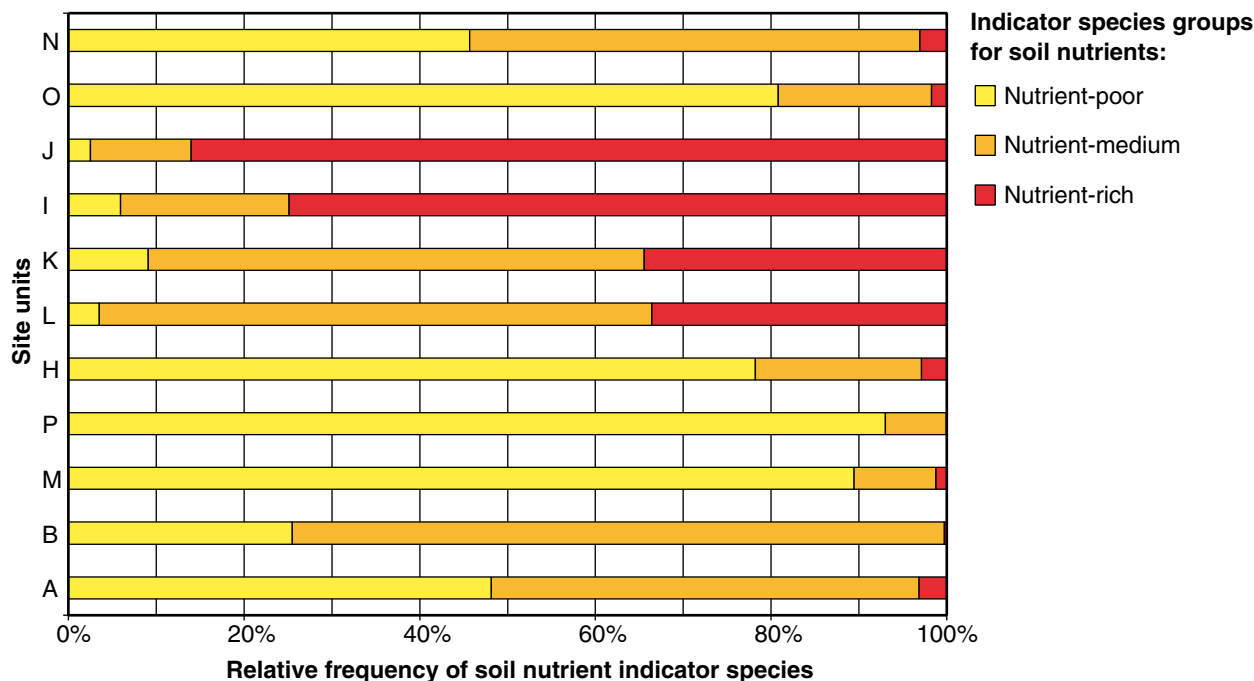
Figure 3.4.4. Soil nutrient spectra for the non-forested site units in the parkland MH subzones. Percent values denote relative frequencies. Forested site groups (C,D,E,F, and G) are included in Figure 3.4.10; codes for site units as in Table 3.4.1.

Forested MH Subzones

Using our vegetation classification, we framed 19 site associations (Table 3.4.2). Except for two cases, each site association was derived from a single plant association or subassociation. The exceptions are the HmSs – Reedgrass and HmYc – Twistedstalk site associations, which were derived from the Tsuga mertensiana – Vaccinium ovalifolium: Calamagrostis nutkaensis plant subassociations. Considering its wide soil moisture range we recognized a slightly dry to fresh and a moist site association. Each site association has an exclusive range of climate, soil moisture and soil nutrient regimes, and sometimes other environmental characteristics. Thus, regardless of the vegetation present on the site (or the stage in stand development), any site within the forested MH subzones can be identified, *i.e.*, assigned to one of the 19 site associations based on the climate and an estimate of soil moisture and nutrient conditions of the site, occasionally aided by an additional environmental property. The environmental individuality of all site associations is illustrated on the environmental matrix (Figure 3.4.5), which provides an overview in relation to climate and edaphic conditions, and on the edatopic grids for the MHwh subzone and the MHmm and MHms variants, which provide an overview in relation to edaphic conditions (Figures 3.4.6, 3.4.7, and 3.4.8). Two generalized topographic sequences for the MHwh and Mhmm-s subzones illustrating the relationships between site associations on the landscape are shown in Figure 3.4.9. By comparison with other site associations, the soil moisture and soil nutrient spectra offer vegetation-inferred information about soil moisture and nutrient conditions for each site association (Figures 3.4.10 and 3.4.11).

The site classification presented here differs slightly from that used in the field guides for the Vancouver and Prince Rupert Forest Regions (Banner *et al.* 1993; Green and Klinka 1994). Differences include minor changes in nomenclature and the edaphic boundary between 'nutrient-poor' and 'nutrient-rich' site associations. The changes in the site associations are the result of a new vegetation classification, which included additional samples from the Prince Rupert and Vancouver Forest Regions, and the change in the edaphic boundary is the result of a recent study by Splechtna (2000) and indicator plant analysis. Originally the 'nutrient-poor' associations included the very poor, poor and medium SMRs, and 'nutrient-rich' associations included the rich and very rich SNRs. The present report limits the 'nutrient poor' associations to very poor and poor SNRs and the 'nutrient-rich' associations to medium and rich SNRs (Figures 3.4.5, 3.4.6, 3.4.7, and 3.4.8).

The MHwh subzone has a more or less unique set of site associations, although nutrient-rich site associations of the MHmm-s subzone also occur in the coastal mainland portion of the MHwh subzone (Figures 3.4.5 and 3.4.6). There are 6 site associations that are distributed across the entire forested MH zone: HmYc – Rhacomitrium, Hm – Copperbush, Hm – Crowberry, HmYc – Deer-Cabbage, Hm – Sphagnum, and HmYc – Skunk Cabbage (Figure 3.4.5). There are 13 nutrient-poor site associations and 8 nutrient-rich forested site associations (Figure 3.4.5). The nutrient-poor site associations generally range from the very poor to poor SNRs, while the nutrient-rich site associations range from the medium to rich SNRs, and infrequently to the very rich SNRs. The difference in SNR between these two sets is supported by a soil chemical analysis (see Section 4.6 SOIL NUTRIENT REGIME on page 122) and by a higher frequency of nutrient-rich plant indicators in the soil nutrient spectra of the nutrient-rich site associations (Figure 3.4.10). The mean frequency of nutrient-rich indicators in most 'nutrient-rich' site series (except HmYc – Skunk Cabbage, HmBa – Lady Fern, and HmBl – Lady Fern) was in the range from 0 to 25 %, which implies the range of medium to rich SNRs (Wang 1992). It appears that the occurrence of very rich sites in the MH zone is rare.

When describing site associations, we proposed potential site types using one or two edaphic adjectives to describe aberrant properties in relation to the majority of the sample plots in a particular site association (Table 3.4.3). We do not expect floristic differences between site types, however, if they occur, they probably reflect edaphic differences. For example, a shallow site type will be expected to be drier than moderately deep and deep sites; a gleysolic site type will be associated with mineral soils as compared to an organic site type.

Table 3.4.2. Synopsis of delineated site associations (in bold fonts) and site series derived from forested vegetation units in the forested MH subzones. Non-forested site units (J,N, and O) that may occur in the forested subzones are included in Table 3.4.1. Codes for vegetation units as in Table 3.3.6. Ba - Pacific silver fir; Bl - subalpine fir; Hm - mountain hemlock Yc - Alaska yellow-cedar; Ss - Sitka spruce.

Site association Site series	Parent vegetation unit
Site units with very poor and poor soil nutrient regimes in order of increasing soil moisture	

C HmYc – Rhacomitrium
    MHwh/HmYc – Rhacomitrium
    MHmm/HmYc – Rhacomitrium
    MHms/HmYc – Rhacomitrium
	Tentative site association; not yet adequately sampled

F Hm – Mountain-Heather
    MHwhp/Hm – Mountain-Heather
    MHwh/Hm – Mountain-Heather
	111 Tsuga mertensiana – Cassiope stelleriana plant association

D HmBa – Mountain-Heather
    MHmmp/HmBa – Mountain-Heather
    MHmm/HmBa – Mountain-Heather
	211 Chamaecyparis – Phyllodoce plant association

E HmBl – Mountain-Heather
    MHmsp/HmBl – Mountain-Heather
    MHms/HmBl – Mountain-Heather
	212 Abies lasiocarpa – Phyllodoce plant association

1 Hm – Copperbush
    MHwh/Hm – Copperbush
    MHmm/Hm – Copperbush
    MHms/Hm – Copperbush
	221 Tsuga mertensiana – Cladothamnus pyroliflorus plant association

2 HmBa – Blueberry
    MHmm/HmBa – Blueberry
 	
    MHms/HmBa – Blueberry
	222 Tsuga mertensiana – Vaccinium membranaceum plant association
	222a Tsuga mertensiana – Vaccinium membranaceum: Chamaecyparis nootkatensis plant subassociation
	222b Tsuga mertensiana – Vaccinium membranaceum: Pleurozium schreberi plant subassociation

3 HmBa – Moist Blueberry
    MHmm/HmBa – Moist Blueberry
    MHms/HmBa – Moist Blueberry
	222c Tsuga mertensiana – Vaccinium membranaceum: Streptopus roseus plant subassociation

G Hm – Crowberry
    MHwhp/Hm – Crowberry
    MHwh/Hm – Crowberry
    MHmmp/Hm – Crowberry
    MHmsp/Hm – Crowberry
    MHmm/Hm – Crowberry
    MHms/Hm – Crowberry
	131 Tsuga mertensiana – Empetrum nigrum plant association

4 HmSs – Blueberry MHwh/HmSs – Blueberry	121 Tsuga mertensiana – Vaccinium ovalifolium plant association 121a Tsuga mertensiana – Vaccinium ovalifolium: typic plant subassociation

5 HmYc – Deer-Cabbage
    MHwh/HmYc – Deer-Cabbage
    MHmm/HmYc – Deer-Cabbage
    MHms/HmYc – Deer-Cabbage
	122 Tsuga mertensiana – Fauria crista-galli plant association

6 Hm – Sphagnum
    MHwh/Hm – Sphagnum
    MHmm/Hm – Sphagnum
    MHms/Hm – Sphagnum
	411 Tsuga mertensiana – Sphagnum plant association

Site association	Parent vegetation unit
Site series	

Site units with medium, rich, and (infrequently) very rich soil nutrient regimes in order of increasing soil moisture

7 HmBa – Foamflower
    MHwh/HmBa – Foamflower
    MHmm/HmBa – Foamflower

311a Abies amabilis – Streptopus roseus: Rhytidiopsis robusta plant subassociation

8 HmBl – Valerian
    MHms/HmBl – Valeriana

312a Abies lasiocarpa – Valeriana sitchensis: Vaccinium membranaceum plant subassociation

9 HmSs – Reedgrass
    MHwh/HmSs – Reedgrass

121b Tsuga mertensiana – Vaccinium ovalifolium: Calamagrostis nutkaensis plant subassociation (fresh plots)

10 HmYc – Twistedstalk
    MHwh/HmYc – Twistedstalk

121b Tsuga mertensiana – Vaccinium ovalifolium: Calamagrostis nutkaensis plant subassociation (moist plots)

11 HmBa – Lady Fern
    MHwh/HmBa – Lady Fern
    MHmm/HmBa – Lady Fern

311b Abies amabilis – Streptopus roseus: Tiarella trifoliata plant subassociation

12 HmBl – Lady Fern
    MHms/HmBl – Lady Fern

312b Abies lasiocarpa – Valeriana sitchensis: Athyrium filix-femina plant subassociation

13 HmYc – Marsh-Marigold
    MHwh/HmYc – Marsh-Marigold

121c Tsuga mertensiana – Vaccinium ovalifolium: Caltha leptosepala plant subassociation

14 HmYc – Skunk Cabbage
    MHwh/HmYc – Skunk Cabbage
    MHmm/HmYc – Skunk Cabbage
    MHms/HmYc – Skunk Cabbage

321 Tsuga mertensiana – Lysichiton americanum plant association

Table 3.4.3. Definitions of the diagnostic edaphic properties used to frame site types in mountain hemlock ecosystems. These properties can represent the central concept (*i.e.* typic) of a site type, or when used as an adjective on the site association name, it can describe the aberrant properties of a site type.

Adjective	Definition
Type and degree of expression of soil horizons	
Gleyed	A soil that has a horizon(s) formed under poor drainage (wet and partly anaerobic) conditions which result in the reduction of iron and other elements and in gray colours and/or mottles; the soil belongs to the gleyed subgroups of Brunisols, Luvisols, Podzols, or Regosols.
Gleysolic	A soil that belongs to the Gleysolic order (Orthic or Humic Gleysols).
Organic	A soil that belongs to the Organic order (Folisols, Fibrisols, Mesisols, or Humisols).
Particle size	
Sandy	Texture of the fine earth is sand or loamy sand but not loamy very fine sand or very fine sand; coarse fragments make up <35% by volume.
Loamy	Texture of the fine earth is loamy very fine sand, very fine sand, or finer, but the amount of clay is <35%; coarse fragments are <35% by volume.
Clayey	Fine earth contains ≥35% clay by weight, and coarse fragments are <35% by volume.
Skeletal	Coarse fragments make up ≥35% by volume with enough fine earth to fill interstices >1 mm; this adjective is used together with the particle size classes defined above (sandy, loamy, and clayey).
Fragmental	Boulders, stones, cobbles, gravel, and very coarse sand particles without enough fine earth to fill interstices >1 mm in diameter.
Rooting depth	
Shallow	A soil that has a rooting depth of <30 cm.
Moderately deep	A soil that has a rooting depth of ≥30 cm but <100 cm.
Deep	A soil that has a rooting depth of ≥100 cm.
Landform characteristics	
Rocky	A site with a discontinuous complex of shallow soils <30 cm deep and exposed bedrock on >30% of the ground surface.
Stony	A site that has ≥35% coarse fragments (gravels, stones, boulders) on the ground surface.
Slope	A site that has a slope gradient of ≥35% but <80%.
Steep-slope	A site that has a slope gradient of ≥80%.
Steep-rocky	A site that has a slope gradient of ≥80%, with a discontinuous complex of shallow soils <30 cm deep and exposed bedrock on >30% of the ground surface.
Limestone	A site whose soil development has been influenced by the underlying limestone bedrock.

Very poor and poor sites

		MHwh	MHmm	MHms
Actual soil moisture regime	**MD**	HmYc - Rhacomitrium (C)		
	SD	Hm - Mountain-Heather (F) Hm - Copperbush[1] (1)	Hm - Copperbush (1) HmBa - Mountain-Heather [2] (D)	Hm - Copperbush (1) HmBl - Mountain-Heather [2] (E)
	F	Hm - Mountain-Heather (F) Hm - Crowberry [3] (G)	HmBa - Blueberry (2) Hm - Crowberry[3] (G)	
	M	HmSs - Blueberry (4) Hm - Crowberry [3] (G)	HmBa - Moist Blueberry (3) Hm - Crowberry [3] (G)	
	VM	HmYc - Deer-Cabbage (5)		
	W	Hm - Sphagnum (6)		

Medium to rich (and very rich) sites

		MHwh	MHmm	MHms
Actual soil moisture regime	**MD**			
	SD	HmSs - Reedgrass (9) HmBa - Foamflower[1] (7)	HmBa - Foamflower (7)	HmBl - Valerian (8)
	F			
	M	HmYc - Twistedstalk (10) HmBa - Lady Fern[1] (11)	HmBa - Lady Fern (11)	HmBl - Lady Fern (12)
	VM	HmYc - Marsh-Marigold (13) HmBa - Lady Fern[1] (11)		
	W	HmYc - Skunk Cabbage (14)		

[1] only in the mainland portion of the MHwh subzone
[2] only at the upper elevation limit of the MH parkland
[3] only at the upper elevation limit of the MH parkland on flat terrain

Figure 3.4.5. Forested site associations delineated in the forested MH subzones in relation to climate (subzones/variants), soil moisture, and soil nutrients. The non-forested site groups (J,N, and O) are included in Figure 3.4.1.

Figure 3.4.6. Edatopic grid illustrating relationships of the site series in the Wet Hypermaritime Forested MH (MHwh) subzone to soil moisture, soil nutrients, and, if appropriate, an additional differentiating site factor. The non-forested site groups (J,N, and O) are included in Figure 3.4.1.
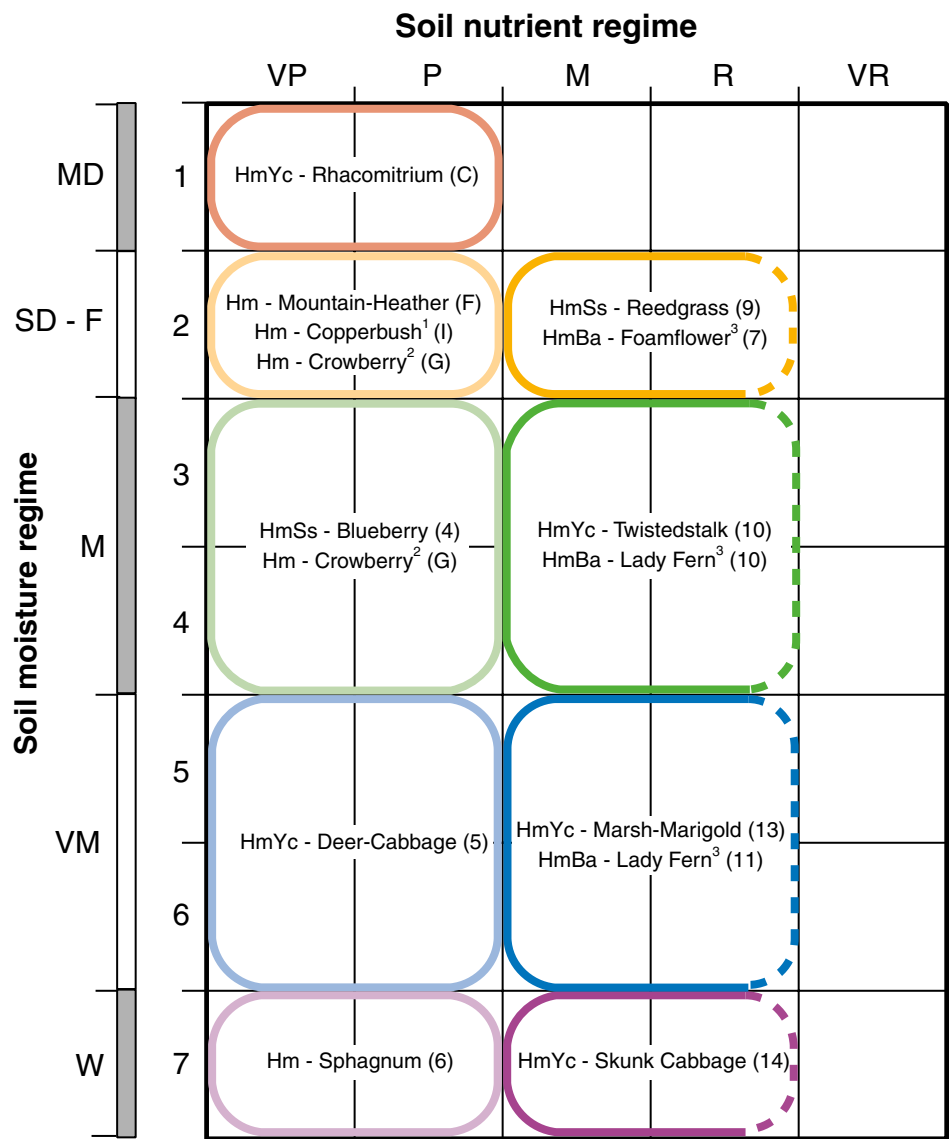
[1] only in the mainland portion of the MHwh subzone on slightly dry sites
[2] only on fresh to moist sites at the upper elevation limit of the MHwh subzone on flat terrain
[3] only in the mainland portion of the MHwh subzone

Soil nutrient regime
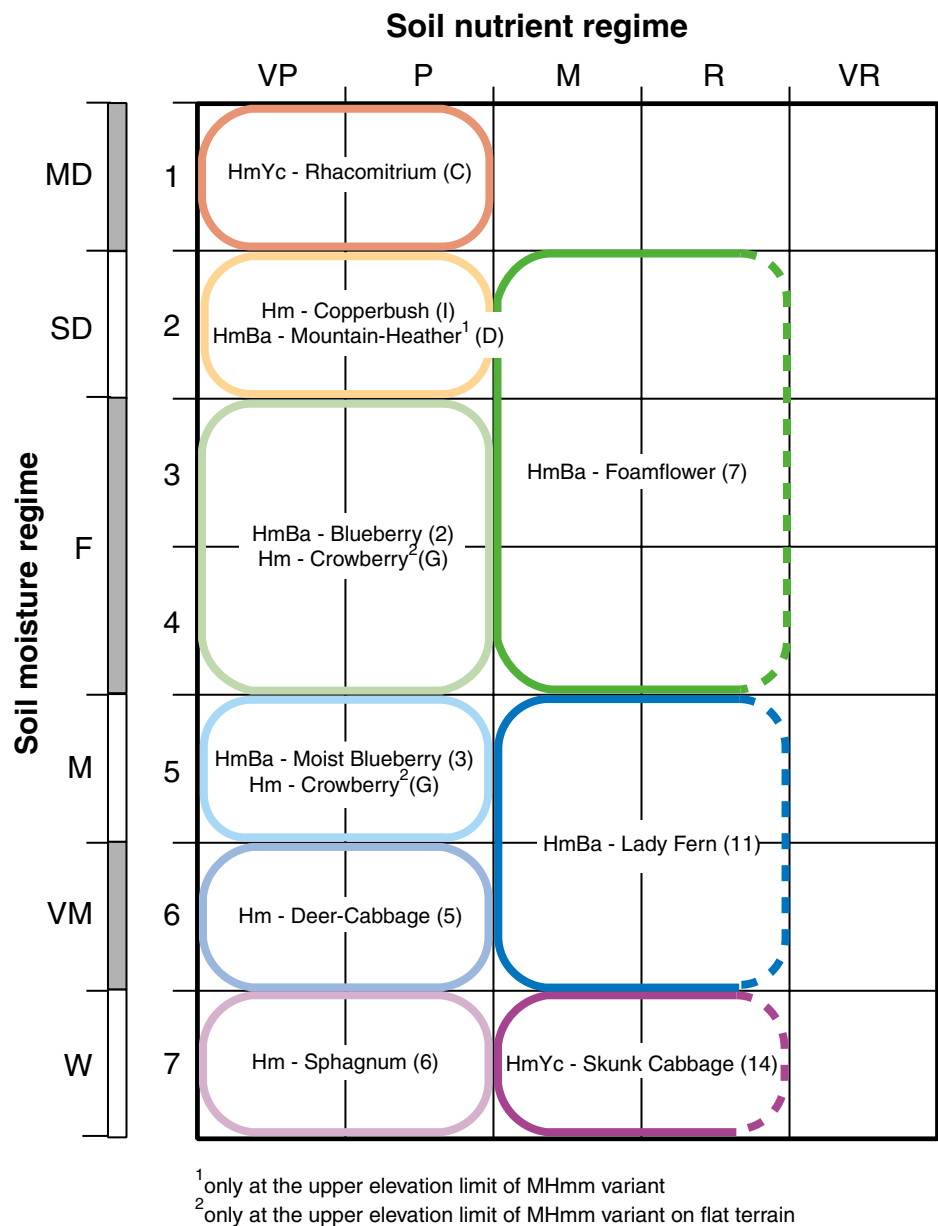
Figure 3.4.7. Edatopic grid illustrating relationships of the site series in the Moist Maritime Forested MH (MHmm) variant to soil moisture, soil nutrients, and, if appropriate, an additional differentiating site factor. The non-forested site groups (J,N, and O) are included in Figure 3.4.1.

Soil nutrient regime
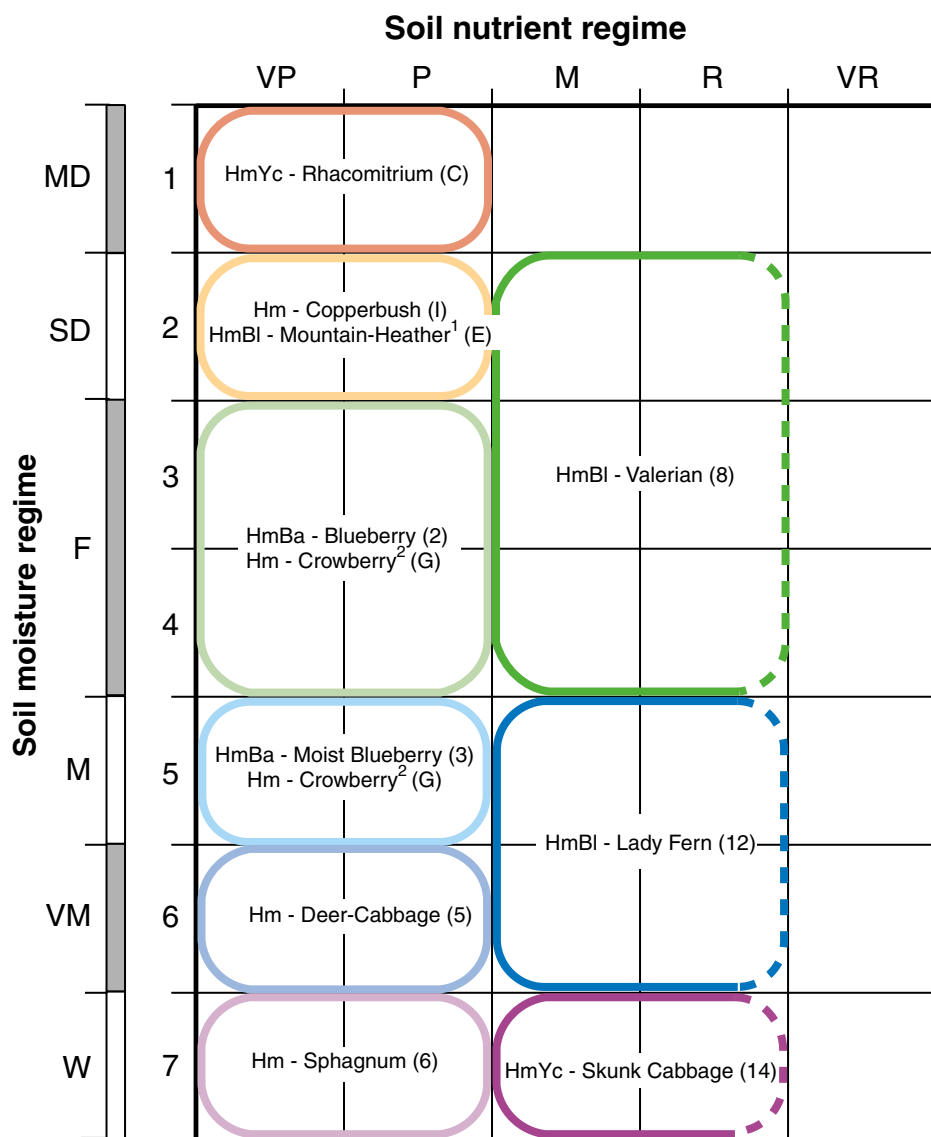
[1]only at the upper elevation limit of the MHms variant
[2]only at the upper elevation limit of the MHms variant on flat terrain

Figure 3.4.8. Edatopic grid illustrating relationships of the site series in the Moist Submaritime Forested MH (MHms) variant to soil moisture, soil nutrients, and, if appropriate, an additional differentiating site factor. The non-forested site groups (J,N, and O) are included in Figure 3.4.1.
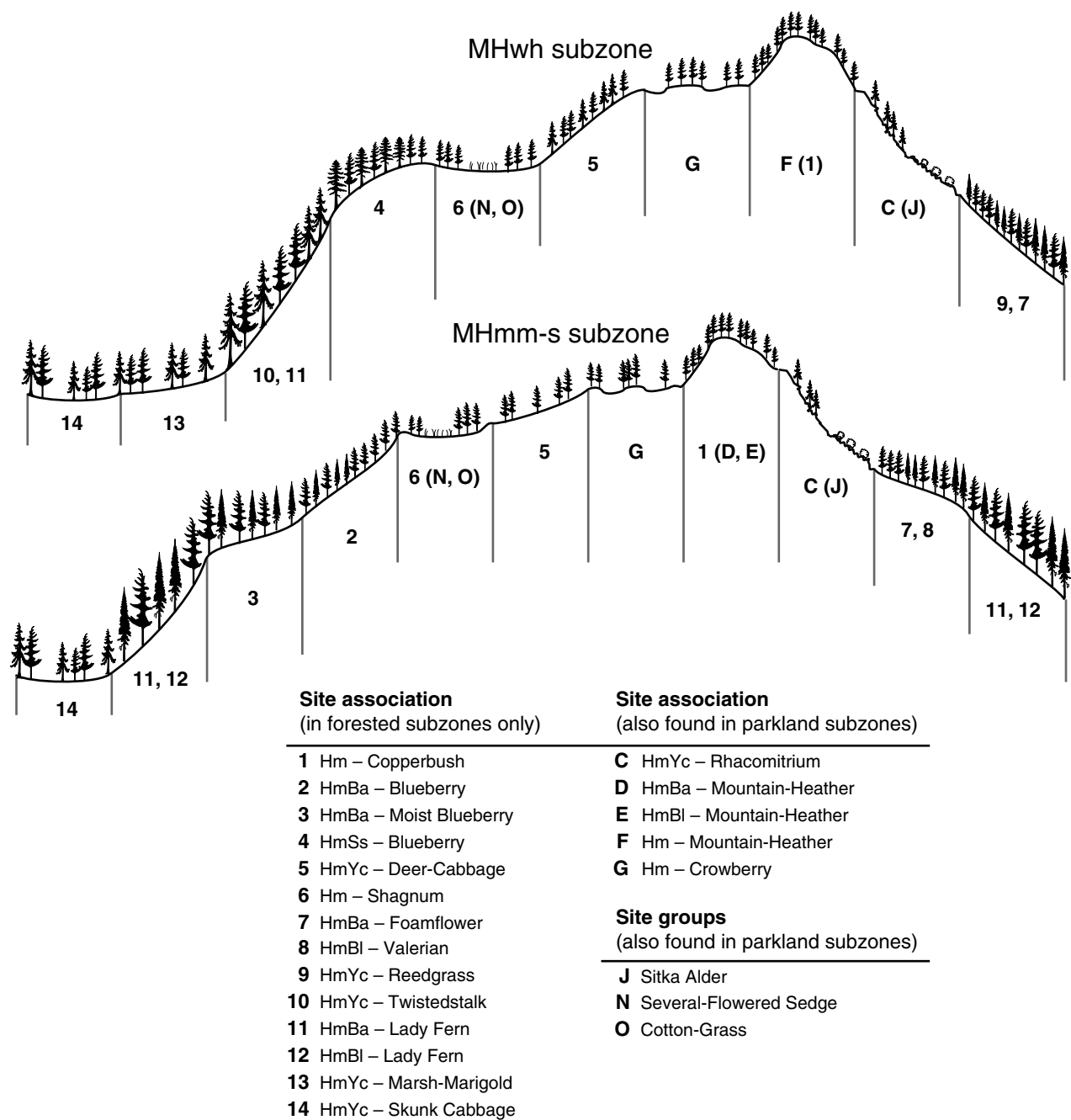
Figure 3.4.9. Generalized topographic sequences showing relationships among site associations for the forested MH subzones.
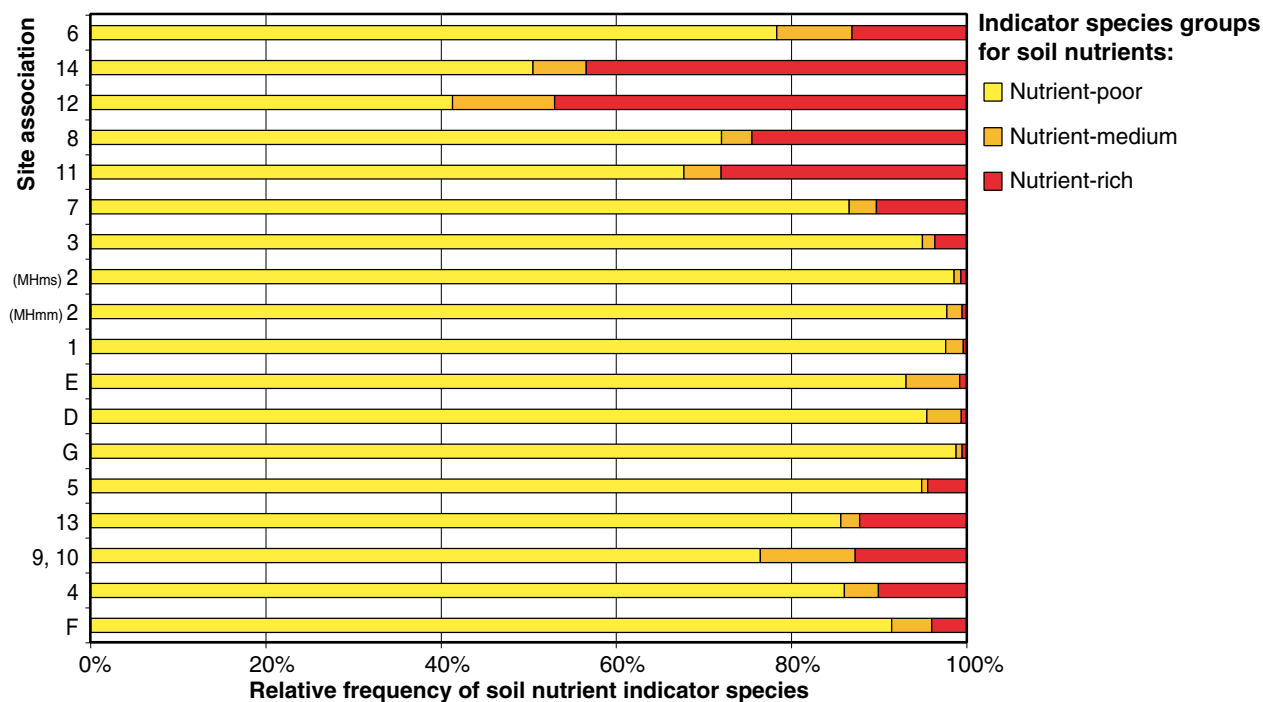
Figure 3.4.10. Soil nutrient spectra for the site associations in the forested MH subzones. The non-forested site groups (J,N, and O) are included in Figure 3.4.4. Percent values denote relative frequencies; codes for site associations as in Table 3.4.2.
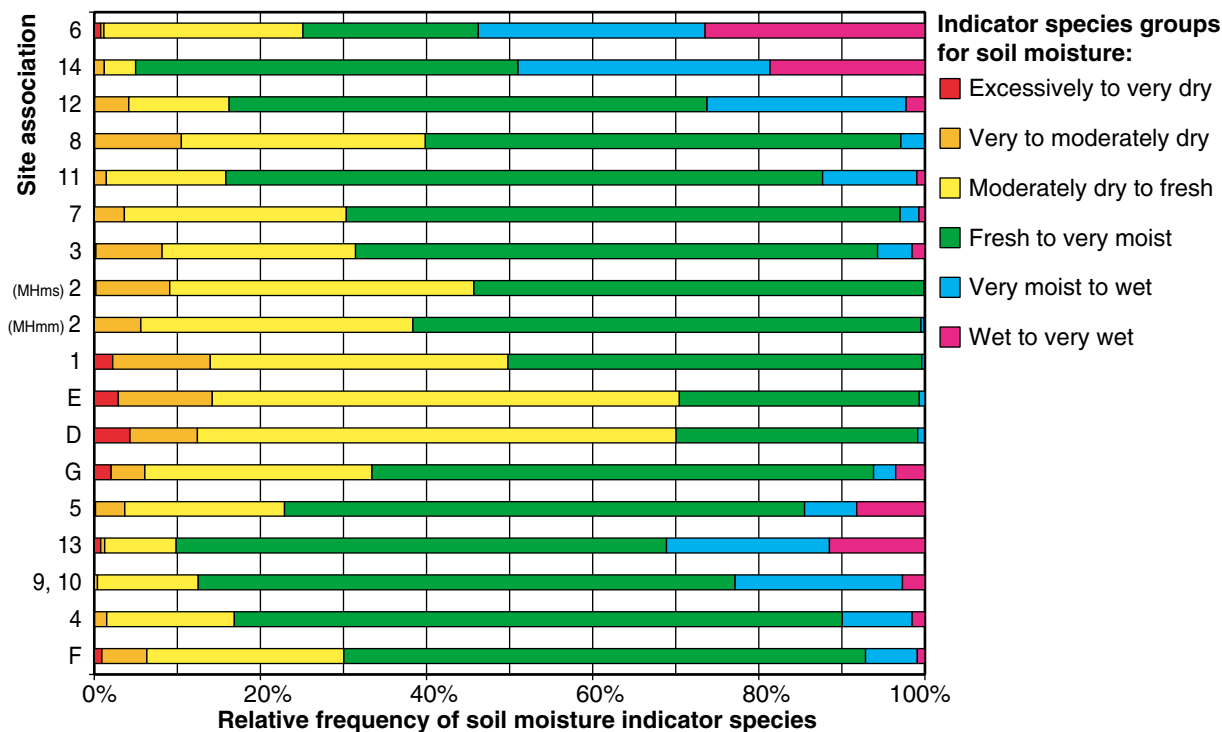
Figure 3.4.11. Soil moisture spectra for the site associations in the forested MH subzones. The non-forested site groups (J,N, and O) are included in Figure 3.4.3. Percent values denote relative frequencies; codes for site associations as in Table 3.4.2.

3.5 DESCRIPTION OF THE SITE UNITS

This section expands upon the vegetation and site classification by describing the important vegetation and environmental (habitat) features of each delineated site unit. The description follows the order given in the synoptic tables for site units (Tables 3.3.1 and 3.3.2). Since the vegetation classification is an expansion of previous studies, we refer to the vegetation units that have been previously described and note whether or not they have been modified. We emphasize the habitats of individual units more than their vegetation for two reasons. The floristic information is presented in diagnostic and summary tables, and also the plant community that will be present on a site can often be inferred from the environmental conditions, or habitat, on that site. The descriptions presented for non-forested sites are based on Brett *et al.* (2001).

Site Units of the Parkland MH Subzones

Rhizocarpon (A) site group

(References: Tables 3.3.2, 3.3.3, and 3.4.1; Figures 3.3.1, 3.4.1 to 3.4.4, and 3.5.1 to 3.5.4)

Moderately dry, exposed rock walls, rock bluffs, and ridges with early snow melt at the upper elevation limit of the MHmm-sp subzone

Some of the driest and most nutrient-poor parkland sites are inhabited by evergreen shrubs, bryophytes, lichens, and/or dwarf woody plants that comprise the communities of the Rhizocarpon geographicum plant order. This order includes the Sibbaldia procumbens, Silene acaulis, Penstemon davidsonii - Juniperus communis, and Phyllodce - Abies lasiocarpa plant associations that represent rupicolous (exposed rock) communities on acidic rocks. These communities are characterized by *Polytrichum piliferum*, and two lichens, *Rhizocarpon geographicum* and *Umbilicaria proboscidea*. These two lichens are also present on rocky sites of the Sibbaldia procumbens association which, due to moisture from late-lying snow, are subject to less moisture stress. The four associations remain unchanged from those first described in Archer's (1963) study of alpine plant communities.

Archer (1963) included the Sibbaldia procumbens association within his 'snow patch' grouping, a grouping that also included snow basin communities of the Marsupella brevissima and Carex nigricans plant orders. These usually flat and exposed sites are snow-free for as little as 2.5 months, but the well-drained Regosols prevent the anaerobic conditions that can prevail in snow basins. Soils are thin, acidic, and consist mostly of accumulations of grit and sand in cracks between rocks. It is these microsites that support pure communities of *Sibbaldia procumbens*, with interspersed *Antennaria alpina*, *Juncus drummondii*, *Luetkea pectinata*, and *Polytrichum piliferum*.

The Silene acaulis and Penstemon davidsonii - Juniperus communis associations were included by Archer (1963) in his 'rupicolous' group, *i.e.*, communities that inhabit Lithosols (Kubiëna 1953). These communities inhabit cracks of rocks where fine organic and mineral debris have accumulated in pockets and depressions. The Silene acaulis association, based on only four plots, is found on recently deglaciated ridges and colluvial slopes where soils retain a relatively high base status. These habitats are usually found in the lee of ridges and couloirs where late snowmelt prevents excessive moisture deficits. Its vigourous taproot system allows *Silene acaulis* to colonize both rock crevices and more open ground, and facilitates survival in unstable soils. Other hardy species found on these harsh sites include *Phacelia sericea*, *Saxifraga bronchialis*, and *Penstemon davidsonii*.

Habitats supporting Penstemon davidsonii - Juniperus communis communities tend to be steeper and more exposed, and moisture deficits in these rock outcrop and ridge-top habitats are more pronounced, than those of the Silene acaulis communities. Exposure to wind severely stunts the height growth of *Juniperus communis* and *Penstemon davidsonii* and results in dwarf shrubs that are usually <10 cm tall. *Phyllodoce glanduliflora* is

common on most sites, and the presence of some *Carex spectabilis* (presumably on moister microsites) indicates an affinity to chomophytic (fragmented rock) communities.

The only krummholz communities described were located on steep sites in the transition between the AT and MH zones, where snow melted as early as the end of June. Archer (1963) named this association 'Abieteto - Chamaecyparetum nootkatensis' to reflect the greater presence of *Abies lasiocarpa* than *Chamaecyparis nootkatensis* or *Tsuga mertensiana*. The presence of such krummholz communities dominated by *Abies lasiocarpa* increases with greater continentality (though they may also occur on the highest peaks of the leeward mountains of Vancouver Island, *e.g.*, Mt. Cain). Analogous, but more maritime-influenced communities with a high cover of *Chamaecyparis nootkatensis* or *Tsuga mertensiana* have yet to be described. This is the only association of the Rhizocarpon geographicum order that develops on Rankers (Kubiëna 1953) or Orthic to Humic Regosols (Agriculture Canada Expert Committee on Soil Survey 1987).

Figure 3.5.1. *Sibbaldia procumbens* is characteristic of rocky sites with longer snow duration than other sites of the Rhizocarpon site group.

Figure 3.5.2. *Silene acaulis* inhabitating a rock pavement.
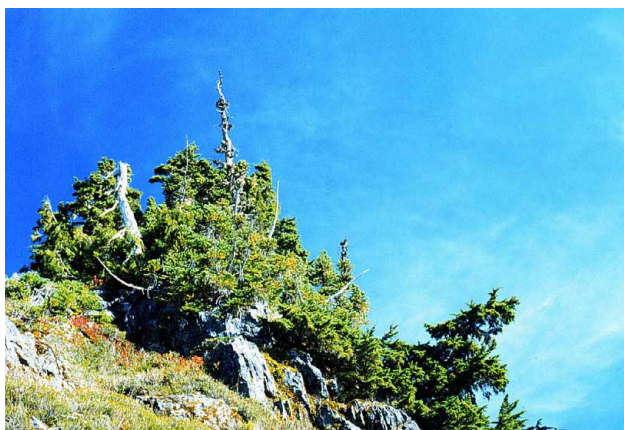
Figure 3.5.3. Subalpine fir krummholz on a rock outcrop on Mt. Cain.

Figure 3.5.4. *Juniperus communis* on a drier rock outcrop.

Phlox (B) site group

(References: Tables 3.3.2, 3.3.3, and 3.4.1; Figures 3.3.1, 3.4.1 to 3.4.4, 3.5.5, and 3.5.6)

Moderately dry, warm-aspect, base-rich, exposed rock walls, rock bluffs, and ridges with early snow melt at the upper elevation limit of the MHmm-sp subzone

The Phlox site group was derived from a single plant association that represents communities occurring on sites similar to the those described for the Rhizocarpon site group, but which are steeper, warmer and have a somewhat longer growing season and base-rich soils. As a result these sites are drier and somewhat richer than the Rizocarpon sites. In addition to *Phlox diffusa*, common species include *Paxistima myrsinites* (on drier microsites) and *Penstemon procerus*. These floristically diverse communities include many species that are absent or rare in other communities including *Lloydia serotina*, *Saxifraga occidentalis*, *Tortella tortuosa*, and *Selaginella wallacei*.

Figure 3.5.5. Phlox sites are usually rocky, base-rich south-aspect slopes.

Figure 3.5.6. *Penstemon procerus* among *Phlox diffusa* on a lithic Phlox site.

Mountain Hemlock Zone

HmYc – Rhacomitrium (C) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5 to 3.4.9, and 3.5.7)

Lower to upper subalpine, moderately dry, very poor and poor, precipitous rock bluffs throughout the MH zone

Although frequent in the montane and subalpine landscapes, Rhacomitrium sites have not yet been adequately sampled. They have been mapped by B.A. Blackwell and Associates Ltd. (2000) in both parkland and forested MH subzones and were designated as Yc – Rhacomitrium bluffs. The central edaphic concept (typic site type) is represented by very shallow, discontinuous soils, typically a mixture of mineral and organic materials, on excessively steep (>100%) rocky bluffs. In consequence, these sites have a marginal snowpack.

The HmYc – Rhacomitrium site association represents a complex of non-productive sites capable of supporting only discontinuous, stunted growth of mountain hemlock and Alaska yellow-cedar. The sites are precipitous cliffs and bluffs with narrow ledges, reefs, crevasses, crevices, and other irregularities. Surface flow of fine material (humus flow) captured in fissures and cracks and deposited on ledges represent a marginal addition of nutrients to the soils. During and shortly after rainfall there is intermittent surface and subsurface seepage over the exposed rock surfaces and underneath the shallow soil layer; however, the soil soon becomes dry. Extreme microsite variation in soil moisture and nutrients is reflected in the complex vegetation pattern, which features a mixture of xerophytic and hygrophytic species, and oxylophytic and nitrophytic species, respectively. In general, saxicolous (rock-inhabiting) bryophytes are the predominant life form. The effect of humus flow is particularly expressed in drainages, where an herb layer may develop.

The soil is persistently removed by degradational geomorphic processes. Trees can only root in deep fissures and cracks between rocks which act as traps for the surface flow of water and material being moved by gravity. Surface runoff concentrates in many intermittent drainages, which erode easily because of thin accumulations of fine materials. Steady displacement and mixing of the shallow soil layer by snow movement, raindrop splash in exposed places, runoff waters, solifluction, creep, and other forms of mass wasting are characteristic features of these sites.

Figure 3.5.7. HmYc – Rhacomitrium bluffs on central Vancouver Island (photo: R.G. Green).

HmBa – Mountain-Heather (D) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5, 3.4.7, 3.4.9, 3.4.10, 3.4.11 and 3.5.8)

Slightly dry to fresh, very poor and poor sites in the MHmmp variant and marginally at the upper elevation limit of the MHmm variant

These sites are forested, but trees occur in clumps (tree islands) and less often in open-canopy stands. They occupy water-shedding exposed ridges and upper slopes where snow duration is relatively short compared to other sites. The central edaphic concept (typic site type) is represented by shallow, often discontinuous, organic or mineral soils with exposed bedrock. Typical soils are thin Folisols over bedrock; mineral soils are well developed Podzols with a high proportion of decaying wood in the forest floor. A lower snowpack, and the topographic and soil conditions of these sites, generally results in slightly dry soil moisture conditions and very poor soil nutrient conditions.

The HmBa – Mountain-Heather site association represents very low-productivity sites capable of supporting only marginal growth of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar, which are often distorted. Alaska yellow-cedar is often reduced to shrub form or is absent from exposed sites at the upper elevation limit of the variant, but can form a major component of the canopy layer of tree islands at the lower elevation limit. Deciduous shrubs and dwarf woody plants dominate the understory vegetation. The diagnostic species include *Phyllodoce empetriformis, Cassiope mertensiana,* and *Luetkea pectinata*. The fringes of these tree islands are often populated by *Vaccinium membranaceum*, *Rhododendron albiflorum* and, in the transition to non-forested communities, *Phyllodoce empetriformis*.

Figure 3.5.8. Tree island on a HmBa – Mountain-Heather site.

HmBl – Mountain-Heather (E) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5, 3.4.8 to 3.4.11 and 3.5.9)

Slightly dry to fresh, very poor and poor sites in the MHmsp variant, and marginally at the upper elevation limit of the MHms variant

Similar to the HmBa – Mountain-Heather site association, these water-shedding sites are forested but trees occur in clumps (tree islands), rarely in open-canopy stands. Trees inhabit exposed ridges and upper slopes where snow duration is relatively short compared to other sites. The central edaphic concept (typic site type) is represented by shallow, often discontinuous organic or mineral soils with exposed bedrock. Typical soils are thin Folisols over rock; mineral soils are well developed Podzols with a high proportion of decaying wood in the forest floor. A lower snowpack, and the topographic and soil conditions of these sites generally result in slightly dry to fresh soil moisture conditions and very poor soil nutrient conditions.

The HmBl – Mountain-Heather site association represents very low-productivity sites capable of supporting only marginal growth of mountain hemlock and subalpine fir (occasionally a dominant tree); the presence of Pacific silver fir and Alaska yellow-cedar decreases with increasing continentality. Deciduous shrubs and bryophytes dominate the understory vegetation. Compared to the HmBa – Mountain-Heather communities, these communities have a higher cover of bryophytes and a lower cover of dwarf woody plants. The diagnostic species include *Abies lasiocarpa*, *Phyllodoce empetriformis*, *Cassiope mertensiana*, *Luetkea pectinata,* and *Rhododendron albiflorum*. The fringes of tree islands feature a high cover of *Vaccinium membranaceum, V. deliciosum, Rhododendron albiflorum* and, in the transition to non-forested communities, *Phyllodoce empetriformis*.

Figure 3.5.9. Exposed tree island on a HmBl – Mountain-Heather site.

Hm – Mountain-Heather (F) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5, 3.4.6, 3.4.9 to 3.4.11, and 3.5.10)

Slightly dry to fresh, very poor and poor sites in the MHwhp and MHwh subzones

These water-shedding sites are forested either with occasional clumps of trees (tree islands) in the parkland subzone or open-canopy stands in the forested subzone. Habitats of tree islands in the parkland subzone are narrow, often rocky ridge crests where snow duration is relatively short; in the forested subzone the habitats are similar, but the ridge crests are somewhat flat and the drainage is not excessive. The central edaphic concept (typic site type) is represented by shallow, often discontinuous, organic or mineral soils. Typical soils are Folisols over bedrock, which are characterized as nutrient-poor but without water deficit or surplus.

The Hm – Mountain-Heather site association represents very low-productivity sites capable of supporting only discontinuous, typically scrubby, growth of mountain hemlock and Alaska yellow-cedar. Although communities in this subassociation have the low canopy cover and tree islands characteristic of the high-elevation parkland, they occur at relatively low elevations (< 1000 m) and often include a component of the frost-sensitive *Tsuga heterophylla* and *Thuja plicata*. The understory vegetation is dominated by mosses and dwarf woody plants, such as *Cassiope stelleriana*, *Phyllodoce empetriformis*, *Cassiope mertensiana*, and *Luetkea pectinata*. Most of the understory vegetation occurs clumped around the base of isolated trees or clumps of trees. Other distinguishing species include *Pleurozium schreberi*, *Vaccinium caespitosum*, and the lichens *Cladina rangiferina* and *C. mitis*. The presence of *Coptis aspleniifolia*, *Fauria crista-galli*, and *Veratrum viride* suggests fresh soil moisture conditions. With the exception of *Cassiope stelleriana*, the floristic composition is much more similar to that on zonal forested sites (HmSs – Blueberry site association) than to the analogous parkland HmBa – Mountain-Heather site association.
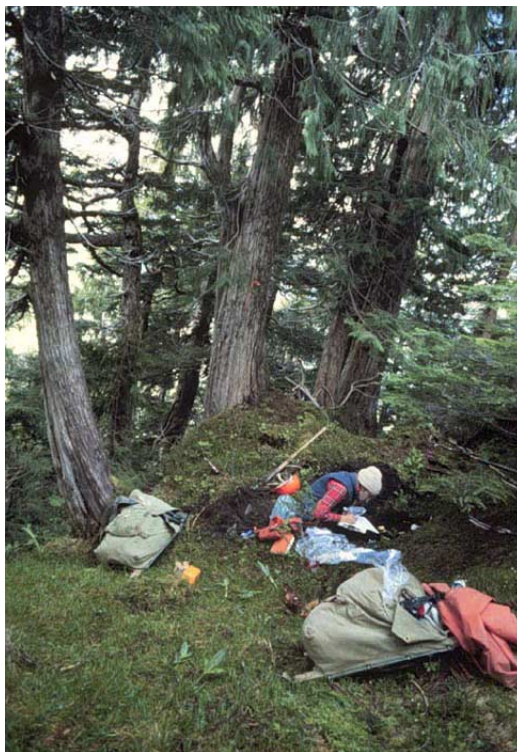

Figure 3.5.10. A clump of Alaska yellow-cedar and mountain hemlock on a Hm – Mountain-Heather site (photo: J. Pojar).

Hm – Crowberry (G) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5 to 3.4.11, 3.5.11 and 3.5.12)

Fresh to moist, very poor and poor sites on flat terrain at the lower elevation limit of parkland subzones and the upper elevation limit of forested subzones

Hm – Crowberry sites support marginal forest growth, however, they typically feature open-canopy stands (less frequently tree islands). Crowberry sites are located on strongly mounded flats or gentle slopes with a higher snowpack and longer snow duration than mountain-heather sites. Trees inhabit mounds, while shrubs, bryophytes, lichens, and dwarf woody plants inhabit treeless areas. The central edaphic concept (typic site type) is represented by shallow to moderately deep organic or mineral soils. The soils are usually a complex of shallow Humic and Hemic Folisols over granitic bedrock or well-developed Podzols. A high proportion of decaying wood in the forest floor signifies very poor soil nutrient conditions.

Mountain hemlock and Alaska yellow-cedar dominate the tree layer; Pacific silver fir is infrequent and when present, has a low vigour. Overall, the understory vegetation features a mixture of xerophytic, mesophytic and hygrophytic species indicating high microsite variability; however hygrophytic plants predominate. The diagnostic species, which occur in canopy gaps, include *Cassiope mertensiana, Empetrum nigrum, Phyllodoce empetriformis, Kalmia microphylla, Pleurozium schreberi, Sphagnum girgensohnii, Vaccinium caespitosum*, and *Vaccinium mebranaceum*. The common species associated with trees include *Cornus canadensis, Pleurozium schreberi, Blechnum spicant*, and *Hylocomium splendens*.

Figure 3.5.11. Hm – Crowberry site with a tree island stand structure indicating a climatic localism in the MHmm variant.

Figure 3.5.12. Open-canopy stands are typical for Hm – Crowberry sites.

Mountain-Heather (H) site group

(References Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4, and 3.5.13)

Slightly dry to moist, very poor to poor, mid-slope sites in the MHmm-sp subzone

The Mountain-Heather site group represents several varieties of well-defined heather communities, which are dominated by dwarf woody plants and mosses. Similar communities have been described in Europe (Nordhagen 1937; McVean and Ratcliffe 1962; Dahl 1956; Rodwell 1991) and in the Pacific Northwest (see Franklin and Dyrness 1988; Viereck *et al.* 1992). Archer (1963) considered heath communities of this order to be the zonal for the AT zone, but the habitat of such heath communities changes with elevation. At higher elevations, they occupy relatively early-snowmelt sites and are slightly snow-avoiding (chionophobous). At lower elevations, such in the MH parkland, they occupy relatively late-snowmelt sites instead and are chionophilous (Brooke *et al.* 1970). They occur on gentle mid-slopes and flat benches where snow melts late and growing conditions resemble those at higher elevations; thus they could be considered to occupy zonal sites in the MH parkland.

Most communities included into this site group have a dense and matted cover of dwarf woody shrubs, occasionally featuring dwarfed mountain hemlock, prostrate Alaska yellow-cedar, and scattered *Vaccinium deliciosum* and *V. membranaceum*, especially in transitions to krummholz or tree islands. The most important diagnostic species are *Phyllodoce empetriformis*, *Cassiope mertensiana*, *Lycopodium sitchense* and, on somewhat wetter sites, *Luetkea pectinata*.

The Mountain-Heather site group also includes Luetkea pectinata communities on grits and coarse sands. Rapid drainage on these usually colluvial slopes is offset by moisture from melting snow. These communities likely represent the initial successional stage on alpine sites. The accumulation of organic material and stabilization of the soil resulting from colonization by these communities eventually results in succession to zonal heath communities.

Figure 3.5.13. A Mountain-Heather site in a canopy gap with late snowmelt in the lower parkland near Yale Creek, with growing conditions similar to higher elevations.

Valerian (I) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4, and 3.5.14)

Fresh to very moist, rich to very rich meadows on mid- and lower slopes in the MHmm-sp subzone

The Valerian site group represents lush herbaceous meadow communities typically associated with colourful floral displays. These herb-dominated communities include a great diversity of short and tall herbs, and occasionally, an abundance of graminoids and mosses. They occur on mid- and lower slopes with plentiful moisture, usually from snowmelt, but also on fresh to moist avalanche tracks or active slide slopes. The associated soils are shallow to deep, rich to very rich, Eutric or Melanic Brunisols developed from base-rich parent materials.

Brett *et al*. (2001) delineated four plant associations on these sites: Parnassia fimbriata – Valeriana sitchensis, Heracleum lanatum – Valeriana sitchensis, Carex spectabilis – Valeriana sitchensis, and Sphagnum – Valeriana sitchensis. The species common to all of them are *Carex spectabilis, Valeriana sitchensis, Heracleum lanatum, Senecio triangularis,* and *Veratrum viride*.

Figure 3.5.14. A slide slope near Hurley Pass that was sampled after the first snowfall in mid-September. The herb-dominated community, which is typical of the Valerian site group, has been flattened by snow.

Sitka Alder (J) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4 and 3.5.15)

Fresh to very moist, rich to very rich avalanche tracks throughout the MH zone

The Sitka Alder site group includes communities that are floristically similar to those in the Valerian site group due to the variety of herbaceous species; however, in addition to herbs, the Sitka alder communities feature a high proportion of deciduous shrubs and ferns. Brett *et al.* (2001) delineated these associations in order of increasing plant vigour and soil nutrients: Phyllodoce empetriformis – Alnus viridis, Juncus ensifolius – Alnus viridis, Valeriana sitchensis – Alnus viridis, and Oplopanax horridus – Alnus viridis. All these communities occur in the landscape in a variably complex pattern depending on the variation in substrate, soil moisture conditions, duration of snowpack, and the frequency of disturbance. The species common to all of these communities are *Alnus viridis, Athyrium filix-femina, Oplopanax horridus, Rubus spectabilis, Sambucus racemosa*, and *Streptous roseus*.

The avalanche track communities are often disturbed by avalanches and thus represent disclimax vegetation. The shrub layer of Sitka alder can be extremely dense, often forming impenetrable thickets, with the stems deformed by the heavy snow cover. Scattered individuals or clumps of mountain hemlock and Alaska yellow-cedar may also be present, although they are confined to canopy gaps and the edges of boulders or small topographic prominences. The associated soils are typically moist to very moist, very rich, skeletal Regosols or Brunisols with Moder or Mull humus forms, that have a high proportion of coarse fragments intermixed throughout the soil profile.

Figure 3.5.15. A dense canopy of *Alnus viridis* is typical of avalanche tracks belonging to the Sitka Alder site group. Note the deformation of stems caused by snow creep.

Swamp Moss (K) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4, 3.5.16 and 3.5.17)

Very moist, medium to very rich springs, seeps, and stream-edge sites in the MHmm-sp subzone

The Swamp Moss site group also represents floristically diverse communities similar to those in the Valerian and Sitka Alder site groups. These herb- and moss-dominated communities develop near flowing water, mostly on upland sites. They form a narrow band on either side of streams and small rivulets, and also develop on seeps (flush habitats) with flowing surface water. In addition to herbs and graminoids, hygrophytic and hydrophytic bryophytes, of which the strikingly yellow-green *Philonotis fontana* is the most prominent, form a constant component. The two distinguished associations (Caltha leptosepala – Leptarrhena pyrolifolia and Epilobium latifolium – Mimulus lewisii) can be segregated by the degree of soil development: no or very little development in the latter, and somewhat greater development (especially the accumulation of more organic material) in the former.

The Caltha leptosepala – Leptarrhena pyrolifolia communities develop where slower-moving water allows the accumulation of fine soil materials, while the Epilobium latifolium – Mimulus lewisii communities develop along braided streams on 'micro'-floodplains, along fast-moving streams and rivulets, and in very vigorous seep areas. Mimulus lewisii can establish where the water table is highest, while *Epilobium latifolium* is more common on slightly raised microsites. Species common to both associations include *Carex nigricans, Juncus drummondii, Carex spectabilis, Caltha leptosepala, Epilobium anagallidifolium, Erigeron peregrinus, Leptarrhena pyrolifolia, Philonotis fontana*, and *Valeriana sitchensis*. Floristically similar communities were identified in alpine meadows of the Washington Cascade Range by Douglas (1970). The Philonotis fontana plant order appears to be closely related to the Montio – Cardaminetalia described in Europe (Krajina 1933; Braun-Blanquet 1951; McVean and Ratcliffe 1962; Shimwell 1971; Ellenberg 1988; Rodwell 1991).

Figure 3.5.16. *Philonotis fontana* (middle of photo) signifies the presence of an active seepage area on a Swamp Moss site on Black Tusk.

Figure 3.5.17. Communities of the Epilobium latifolium – Mimulus lewisii association are initial colonizers of stream-edge Swamp Moss sites with fast-flowing water (Brandywine Meadows).

Showy Sedge (L) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4 and 3.5.18)

Slightly dry to very moist, medium to rich talus slopes, rubble fields, fragmented rocks, and recently exposed moraines at the upper elevation limit of the MHmm-sp subzone

The Showy Sedge site group combines pioneer plant communities that colonize recently deglaciated areas which are usually skeletal and fragmental. These chomophytic (fragmented rock) communities are most common in the AT zone, but also occur at the upper elevation limit of the MH zone where coarse fragment debris has accumulated in late-snowmelt depressions. The associated soils are relatively base-rich because they have yet to be heavily leached or acidified, and have an abundant source of moisture from melting snow. There is little organic accumulation or soil development and Regosols are most common.

Brett *et al.* (2001) delineated three plant associations: Carex spectabilis, Anaphalis margaritacea – Lupinus arcticus, and Oxyria digyna – Carex spectabilis. The Carex spectabilis communities develop on a variety of bouldery sites (*e.g.*, talus, rock outcrops, and glacial outwash slopes), as long as there is a source of moisture, usually melting snow. These plant communities are relatively species-poor. *Carex spectabilis* can form pure, continuous communities on finer-textured soils of volcanic origin. On talus slopes, where boulders and other large fragments restrict colonization, *Carex spectabilis* is more dispersed. *Lupinus arcticus* is also common on most sites, though less abundant than in the following association.

The Anaphalis margaritacea – Lupinus arcticus communities are characteristic of the initial successional stages on recently formed fluvial terraces, moraines, and boulder fields that have not been extensively leached of bases (Archer 1963). *Lupinus arcticus* and *Anaphalis margaritacea* dominate these diverse communities that contain more herbaceous species than almost any other communities in this classification.

The Oxyria digyna – Carex spectabilis communities are found on moist cool-aspect colluvial slopes. The presence of *Petasites frigidus* indicates a constant flow of cold water. Pioneer plant communities with *Oxyria digyna* are also present on somewhat drier sites classified in the Parnassia fimbriata – Valeriana sitchensis association.

Figure 3.5.18. A moist, colluvial Showy Sedge site on Black Tusk.

Marsupella (*M*) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1 to 3.4.4 and 3.5.19)

Slightly dry to moist, very poor to poor sheet-wash and late-snowmelt sites at the upper elevation limit of the MHmm-sp subzone

The Marsupella site group includes chionophilous (late-snowmelt) pioneer and snow basin communities that occur mainly in the AT zone, but can also be found at the upper elevation limit of the MH parkland. These bryophyte-dominated communities develop on sites with a very long-lasting snowpack and they tolerate a nearly continuous saturation of cold melt water. In addition to the cushion moss, *Marsupella brevissima* (= *Gymnomitrium varians*), *Saxifraga tolmiei* is also characteristic of this order.

Brett *et al.* (2001) described three plant associations in this order: Polytrichum alpinum – Marsupella brevissima, Polytrichum piliferum – Marsupella brevissima, and Luzula wahlenbergii – Saxifraga tolmiei. The Polytrichum alpinum – Marsupella brevissima communities occur in the lowest sites with the latest snowmelt in snow basins on protected slopes. Snowmelt occurs near the end of August and the constant cold, anaerobic conditions and annual deposits of fine silt lead to the development of a snow basin Rutmark (Kubiëna 1953) or Orthic or Gleyed Regosol (Agriculture Canada Expert Committee on Soil Survey 1987). Vegetation is seldom taller than 1 cm and consists of pure cushion-like communities of *Marsupella brevissima*, which generally span 1 to 2 m, in the middle of depressions. At the edges of these depressions, *Polytrichum alpinum* occurs on slight (*i.e.,* 1 to 3 cm) prominences that form the transition to *Carex nigricans*-dominated communities.

The Polytrichum piliferum – Marsupella brevissima communities are found on sites where snow melts up to three weeks earlier than in the Polytrichum alpinum – Marsupella brevissima association, and a coarser, sandy soil prevents the same degree of saturation from melting snow. As a result, the cover of the less water-tolerant *Polytrichum piliferum* increases. Loose stones and gravel (Hamada, Kubiëna 1953) and freeze-thaw processes limit soil development to Gleyed Regosols (Agriculture Canada Expert Committee on Soil survey 1987). The pioneer plants *Luzula piperi* and *Saxifraga tolmiei*, are common here, which may indicate a transition to sheet-wash communities of the Luzula wahlenbergii – Saxifraga tolmiei association.

The pioneer Luzula wahlenbergii – Saxifraga tolmiei communities, which are dominated by *Saxifraga tolmiei, Marsupella brevissima,* and *Luzula wahlenbergii*, occur where soil instability and cool temperatures restrict vegetation and soil development. Such communities are found on upper, north-aspect sites that are snow-free for only 2 to 3 months each year. Soil movement is promoted by the continuous saturation of the soil, frost heaving, and sheet-wash (down-slope movement of surface stones and gravels caused by heavy rain), and little or no organic matter accumulates in the soils.

Figure 3.5.19. *Marsupella brevissima* and *Polytrichum alpinum* are characteristic of Marsupella sites, which occupy the micro-depressions of late snowmelt areas in the upper MH parkland.

Several-Flowered Sedge (N) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4 and 3.5.20)

Wet to very wet, very poor to poor wetlands at the lower elevation limit of the MHmm-sp subzone

This 'low-elevation' site group is one of the three site groups representing high-elevation graminoid- and *Sphagnum*-dominated wetlands. The Sphagnum – Carex pluriflora communities inhabiting these sites are species-poor with only 12 species, 6 of which are not found in any other non-forested, high-elevation communities: *Carex pluriflora*, *C. obnupta*, *Sphagnum fallax*, *S. papillosum, Agoseris glauca, Gentiana sceptrum, Sanguisorba officinalis*, and *Vaccinium uliginosum.* These communities inhabit seeps on very gentle slopes where the water table frequently rises above the ground surface. The associated soils are nutrient-poor Cumulic Mesisols. The Carex pluriflora – Sphagnum communities described by Wade (1965) typically inhabit depressions in the center of peat bogs in the hypermaritime climatic region near sea level on the West Coast of Vancouver Island, but they also extend to lower subalpine sites.

Figure 3.5.20. A canopy gap in a lodgepole pine stand dominated by *Carex pluriflora* and *Sphagnum* spp. on an organic Several-Flowered Sedge site.

Cotton-Grass (O) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4, 3.5.21 and 3.5.22)

Wet to very wet, very poor to poor wetlands at the lower elevation limit of the parkland subzones

This 'mid-elevation' site group is one of the three site groups representing high-elevation graminoid- and *Sphagnum*-dominated wetlands. The Eriophorum angustifolium communities inhabiting these sites are dominated by sedges and bryophytes, and commonly form in and around small, stagnant ponds. Brett *et al.* (2001) described three plant associations: Warnstorfia exannulata – Eriophorum angustifolium, Fauria crista-galli – Eriophorum angustifolium, and Carex aquatilis – Eriophorum angustifolium.

The Warnstorfia exannulata – Eriophorum angustifolium communities consist almost solely of *Eriophorum angustifolium* and, on the wettest microsites, *Warnstorfia exannulata*. These communities occupy the lowest portions of many water-collecting sites, which may be inundated throughout the growing season. Organic soils (Fibrisols, Mesisols, and even Humisols) prevail.

The Fauria crista-galli – Eriophorum angustifolium communities are especially common on more maritime sites. These wetland sites may include a mix of typical bog species (*e.g., Kalmia microphylla, Fauria crista-galli, Sphagnum* spp., and *Vaccinium uliginosum*), species usually associated with mesic sites, (*e.g., V. caespitosum* and *Pleurozium schreberi*), and species associated with drier sites (*Cladina rangiferina* and *C. mitis*).

The Eriophorum – Carex aquatilis communities distinguished by Brooke *et al.* (1970) mostly inhabit water-collecting basins in the forested subzones, but may also form at higher elevations, even extending into the AT zone. Accumulations of *Sphagnum subnitens* remains form deep (60-120 cm) peats over gleyed mineral soils. A number of typical wetland species are present only within these communities, including *Carex aquatilis, Drepanocladus aduncus,* and *Calliergonella cuspidata*. Brooke *et al.* (1970) inferred a successional pattern of species, with *Carex aquatilis* in initial stages of development (raised water table), and *Eriophorum angustifolium* and *Sphagnum subnitens* at later stages of development (where the accumulation of organic material decreases water saturation at the surface).

Figure 3.5.21. Cotton-Grass sites are water-collecting, such as this area with standing water in the depressions of a snow basin. The Eriophorum angustifolium community is surrounded by more mesic Alpine Sedge and Mountain-Heather sites.

Figure 3.5.22. Organic soils, in this case a Mesisol, are characteristic of bogs included in the Cotton-Grass site group.

Alpine Sedge (P) site group

(References: Tables 3.3.2, 3.3.3 and 3.4.1; Figures 3.3.1, 3.4.1, 3.4.2 ,3.4.3, 3.4.4, and 3.5.23)

Very moist to wet, very poor to poor wetlands in snow basins in the MHmm-sp subzone

This site group includes the chionophilous sedge- and bryophyte-rich vegetation of semi-terrestrial, snow basin habitats classified as the Carex nigricans plant association. These communities develop below north-aspect slopes and in other basin habitats where cold-air ponding slows snowmelt, so that snow is present for ≥9 months each year. *Carex nigricans* often forms single-species communities around small ponds; snow basins around pits are dominated by *Marsupella brevissima*. The late snowpack and the cold, usually water-saturated, root environment limit vegetation development. Continuous mats of *Carex nigricans* cause turf-like surface soil horizons. Soils are usually fine-textured and laminated with yearly deposits of fine organic and inorganic sediments washed into depressions from snowmelt and from erosion on adjacent slopes and are classified as Gleyed Cumulic Regosols (Agriculture Canada Expert Committee on Soil Survey 1987). On raised microsites and adjacent upland slopes, where snow melts earlier and soils are drier, these communities grade into heath communities of the Cassiope empetriformis – Phyllodoce empetriformis order.

Figure 3.5.23. A typical snow basin sequence (from Mt. Washington). Alpine Sedge sites surround the Cotton-Grass site at the centre, while Mountain-Heather sites occupy still higher ground.

Site Units of the Forested Mountain Hemlock Subzones

HmYc – Rhacomitrium (C) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2 ,3.4.5 to 3.4.9, and 3.5.7)

Lower to upper subalpine, moderately dry, very poor and poor, precipitous rock bluffs throughout the MH zone

The description for this site association is given on page 68.

HmBa – Mountain-Heather (D) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2 ,3.4.5, 3.4.7, 3.4.9, 3.4.10, 3.4.11 and 3.5.8)

Slightly dry to fresh, very poor and poor sites in the MHmmp variant and, marginally, at the upper elevation limit of the MHmm variant

The description for this site association is given on page 69.

HmBl – Mountain-Heather (E) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5, 3.4.8, 3.4.9, 3.4.10, 3.4.11 and 3.5.9)

Slightly dry to fresh, very poor and poor sites in the MHmsp variant and, marginally, at the upper elevation limit of the MHms variant

The description for this site association is given on page 70.

Hm – Mountain-Heather (F) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2 ,3.4.5, 3.4.6, 3.4.9, 3.4.10, 3.4.11 and 3.5.10)

Slightly dry to fresh, very poor and poor sites in the MHwhp and MHwh subzones

The description for this site association is given on page 71.

Hm – Copperbush (1) site association

(References: Table 3.4.2; Figures 3.4.5 to 3.4.11 and 3.5.24)

Slightly dry, very poor to poor, water-shedding sites in the forested subzones

The Hm – Copperbush site association was derived from the Tsuga mertensiana – Cladothamnus pyroliflorus plant association, which is distributed in the coastal mainland portion of the MHwh subzone, the MHmm variant and, less frequently, in the MHms variant. Copperbush sites occur most often at the upper elevation limit of the forested subzones; in the low-elevation parkland sites they grade into the Mountain-Heather sites. The central edaphic concept (typic site type) is represented by shallow, well-drained Folisols or Podzols over bedrock. Copperbush sites support very low-productivity growth of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar. Due to exposed bedrock on ridges and upper slopes, the canopy is discontinuous. The soil moisture regime is slightly dry as a result of lower snowpack, earlier snowmelt, shallow soils, and rapid drainage. The soils may be subject to a higher water deficit in the absence of continuous precipitation. Wind strongly influences the tree layer on crests and upper slopes by removing organic particles and affecting crown development, and is the cause of frequent windthrow. Organic materials tend to accumulate on the ground surface resulting in the development of thick forest floors that sometimes occupy more than half of the soil profile.

Mountain hemlock, Pacific silver fir, and/or Alaska yellow-cedar dominate the semi-open tree layer; the understory vegetation features a high cover of deciduous shrubs (*Vaccinium membranaceum, V. ovalifolium, Cladothamnus pyroliflorus, Phyllodoce empetriformis*) and bryophytes (predominantly *Rhytidiopsis robusta*). The highest cover of shrubs occurs in canopy gaps, typically exposed areas over rock outcrops. A very dense ericaceous understory is characteristic of the open stands dominated by mountain hemlock. For example, the canopy cover is usually <50%, while the cover of shrubs can be >90%. Floristically, the vegetation is most similar to that on the Blueberry sites and the Mountain-Heather sites. With increasing elevation Copperbush sites are replaced by Mountain-Heather sites. This change is manifested in the increasing presence of *Vaccinium deliciosum, Cassiope mertensiana*, and *Luetkea pectinata*.
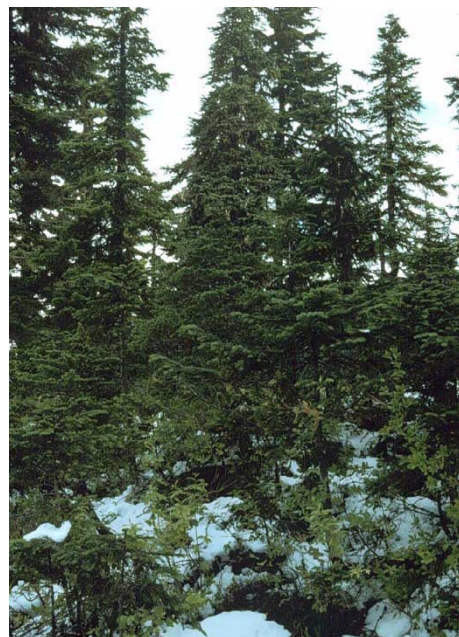

Figure 3.5.24. Distant and close-up views of Hm – Copperbush sites on rocky hill tops.

HmBa – Blueberry (2) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.7, 3.4.9, 3.4.10, 3.4.11, 3.5.25 and 3.5.26)

Fresh, very poor to poor, mid-slope sites in the MHmm-s subzone

The HmBa – Blueberry site association was derived from the Tsuga mertensiana – Vaccinium membranaceum plant association, which is distributed throughout the MHmm-s subzone on intermediate (zonal) sites. The maritime variation is distinguished by a higher presence of Alaska yellow-cedar; the maritime-submaritime variation is distinguished by a higher presence of *Pleurozium schreberi* and increasing presence of subalpine fir (which is still relatively infrequent) along a longitudinal gradient. Compared to other sites, Blueberry sites occur most frequently in the subalpine landscape. They may be associated with a variety of soil parent materials and occupy all slope positions and aspects, but are most frequent on slightly water-shedding mid slopes. Strongly leached Ae soil horizons develop on these sites and soils include both Humo-Ferric and Ferro-Humic Podzols, with occasional Humic Podzols and Folisols. Forest floors can be very thick (often >30 cm) and Hemimor or Humimor humus forms dominate. Abundant moisture from snowmelt and precipitation keep soils near saturation for most of the fall and winter, and temporary seepage prevents moisture deficits during the growing season. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Podzols on intermediate slopes. Aberrant site types may include shallow, stony, steep-slope, steep-rocky, and organic.

Depending on elevation, Blueberry sites support low to medium productivity growth of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar. Higher productivity is reflected by the development of closed-canopy stands with a high basal area, particularly Pacific silver fir stands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Pacific silver fir are most frequent. Western hemlock may be present on steep, warm-aspect slopes, while Alaska yellow-cedar is most common on cool-aspect sites and in true old-growth stands. The understory vegetation is species-poor, especially in high-density stands, and predominantly consists of deciduous shrubs (*Vaccinium ovalifolium, V. membranaceum*, and *Menziesia ferruginea*) and mosses (*Rhytidiopsis robusta*). *Rubus pedatus* and *Orthilia secunda* are the most common herbs.

Figure 3.5.25. A subalpine fir-dominated stand on a stony MHms/HmBa – Blueberry site.
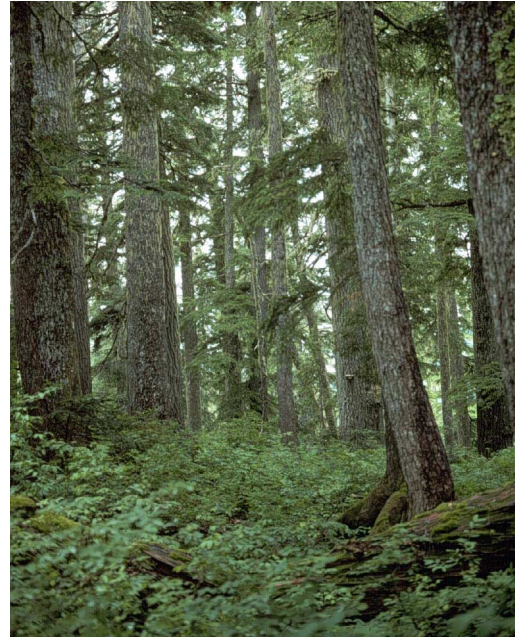

Figure 3.5.26. A uniform stand of mountain hemlock on a MHmm/HmBa – Blueberry site with a well-developed understory of ericaceous shrubs.

HmBa – Moist Blueberry (3) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.7, 3.4.9, 3.4.10, 3.4.11, and 3.5.27)

Fresh, poor, gentle mid- and lower slopes and slightly water-receiving sites in the MHmm-s subzone

The HmBa – Moist Blueberry site association is environmentally and floristically closely related to the HmBa – Blueberry site association, with the former having fresh and somewhat richer (albeit still poor) edaphic conditions. The maritime variation may be distinguished by a higher presence of Alaska yellow-cedar; the maritime-submaritime variation by a minor presence of subalpine fir. Moist Blueberry sites may be associated with a variety of soil parent materials and occupy all slope positions and aspects, but are most frequent on gentle lower slopes. The associated soils include both Gleyed Humo-Ferric and Ferro-Humic Podzols, with occasional Gleyed Humic Podzols and Folisols. Forest floors can be very thick (often >30 cm) and Hemimor or Humimor humus forms dominate. Abundant moisture from snowmelt, intermittent seepage, and precipitation keep soils near saturation for most of the growing season. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Gleyed Podzols on gentle slopes. Aberrant site types may include shallow, stony, slope, and organic.

Depending on elevation, Moist Blueberry sites support medium-productivity growth of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar. Similarly to Blueberry sites, higher productivity is reflected by the development of closed-canopy stands with a high basal area, particularly in Pacific silver fir stands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Pacific silver fir are most frequent. Western hemlock may be present on steep, warm-aspect slopes, while Alaska yellow-cedar is most common on cool-aspect sites. The understory vegetation is species-poor, especially in high-density stands. In addition to mesophytic species that are characteristic of Blueberry sites (*Vaccinium ovalifolium, V. membranaceum, Menziesia ferruginea, Rhytidiopsis robusta, Rubus pedatus, Orthilia secunda*), it includes scattered hygrophytic species, typically *Streptopus roseus* and *Veratrum viride*.
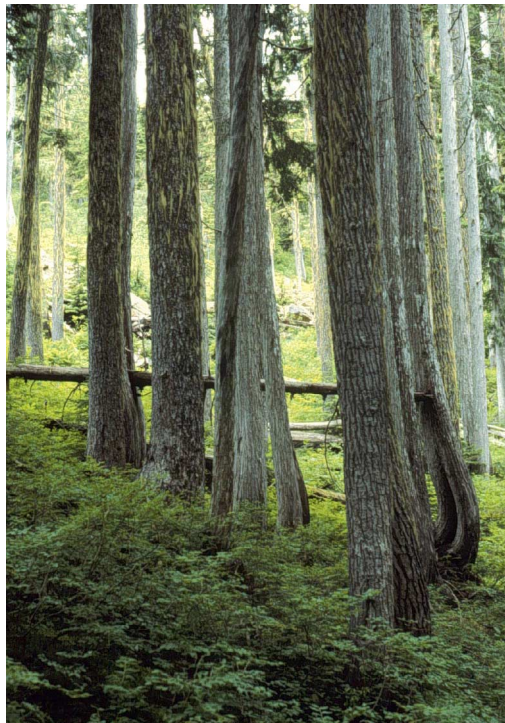

Figure 3.5.27. A mixture of a mountain hemlock and Alaska yellow-cedar on a typic HmBa – Moist Blueberry site.

Hm – Crowberry (G) site association

(References: Tables 3.4.1 and 3.4.2; Figures 3.4.1, 3.4.2, 3.4.5 to 3.4.11 and 3.5.12)

Fresh to very moist, very poor and poor sites on flat terrain at the lower elevation limit of the parkland subzones and the upper elevation limit of the forested subzones

Description for this site association is given on .

HmSs – Blueberry (4) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.6, 3.4.9, 3.4.10, 3.4.11 and 3.5.28)

Moist, poor, steep mid-slopes in the MHwhp subzone

The HmSs – Blueberry site association, which is diagnostic for the MHwh subzone, is distributed on intermediate (zonal) sites throughout the western coast of Vancouver Island, the Central Coast, and the Queen Charlotte Islands. Compared to other hypermaritime forested sites, Blueberry sites are most frequent in the subalpine landscape. They may be associated with a variety of soil parent materials and occupy all slope positions and aspects but are most frequent on steep, water-shedding, upper and mid-slopes associated with morainal or colluvial materials. In spite of relatively rapid drainage, soils remain moist throughout the growing season due to frequent precipitation. Podzols, sometimes with pronounced gleying, are most common, although Folisols may also develop. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Podzols on intermediate slopes. Aberrant site types may include shallow, stony, steep-slope, steep-rocky, and organic types.

Depending on elevation, Blueberry sites support low- (often scrubby) to medium-productivity growth of mountain hemlock, western hemlock, Sitka spruce, and Alaska yellow-cedar. Higher productivity is reflected by the development of closed-canopy stands with a high basal area, particularly hemlock and/or Sitka spruce. Stands of Sitka spruce occur most frequently on the Queen Charlotte Islands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Alaska yellow-cedar are most frequent. The understory vegetation is dominated by bryophytes (*Hylocomium splendens, Plagiothecium undulatum, Rhizomnium glabrescens, Rhytidiadelphus loreus, Rhytidiopsis robusta,* and *Scapania bolanderi*), but often includes ferns (*Blechnum spicant*) and herbs, such as *Coptis aspleniifolia*, *Cornus canadensis*, and *Listera* spp. Deciduous shrubs are less frequent and are represented by *Vaccinium ovalifolium* and *V. parvifolium*. The presence of *Calamagrostis nutkaensis* increases with increasing hypermaritime influence and latitude.

Figure 3.5.28. The understory of old-growth stands on HmSs – Blueberry sites is dominated by bryophytes (mid-slope and flat sites on Queen Charlotte Islands; photo: J. Pojar).

HmYc – Deer-Cabbage (5) site association

(References: Table 3.4.2; Figures 3.4.5 to 3.4.11 and 3.5.29)

Very moist, very poor to poor, water-receiving, lower slopes in the forested subzones

Deer-Cabbage sites support the development of forested communities throughout the forested subzones, with their distribution decreasing from hypermaritime to submaritime climates. These sites occur on mid- and lower slopes, often on toe slopes, less frequently on broad ridge crests. They may have a higher snowpack and longer snow duration than upslope sites, and may feature intermittent or poor drainage. As a result, soil aeration is restricted. The associated soils are a complex of Gleyed Podzols, Gleysols, Mesisols, and Humisols over bedrock. The central edaphic concept (typic site type) is represented by shallow to moderately deep mineral soils; the aberrant type is organic.

Deer-Cabbage sites support low-productivity (often scrubby) growth of mountain hemlock, Sitka spruce (only in hypermaritime climates), and Alaska yellow-cedar. Trees and deciduous shrubs inhabit drier elevation prominences, while herbs and bryophytes inhabit wetter, treeless microsites. Deciduous shrubs, herbs, and mosses dominate the understory vegetation. Deciduous shrubs include *Cladothamnus pyroliflorus* and *Vaccinium ovalifolium*; mosses include *Hylocomium splendens, Plagiothecium undulatum, Rhytidiadelphus loreus*, and *Sphagnum girgensohnii*; herbs include *Coptis aspleniifolia, Cornus canadensis, Fauria crista-galli, Rubus pedatus, Streptopus roseus*, and *Veratrum viride*.

Figure 3.5.29. A lower-slope Deer-Cabbage site surrounding a high-elevation wetland.

Hm – Sphagnum (6) site association

(References: Table 3.4.2; Figures 3.4.5 to 3.4.11 and 3.5.30)

Wet, very poor to poor, water-collecting sites in the forested subzones

Sphagnum sites occur infrequently throughout the forested subzones, with distribution decreasing from hypermaritime to submaritime climates. These sites, usually adjacent to non-forested wetlands, feature multi-storied, open-canopy stands on flat terrain or in depressions, with restricted outflow of excess groundwater. As a result, Sphagnum sites have very poor drainage, deficient soil aeration, a deeper snowpack and longer snow duration than upslope sites. Accumulation of organic material in these sites is more rapid than decomposition. Charcoal, decaying wood, and volcanic ash may be found in the organic soil horizons. Mor humus formation, gleization, and cumulation are the characteristic soil forming processes on Sphagnum sites. The associated soils are Gleysols, Fibrisols, or Mesiosols, rarely Humisols, with a stagnant groundwater table. The central edaphic concept (typic site type) is represented by Humic Gleysols; the aberrant type is organic.

Sphagnum sites support very low-productivity, scrubby growth of mountain hemlock, with or without Alaska yellow-cedar. Trees and deciduous shrubs inhabit drier prominences, while herbs and bryophytes inhabit wetter, treeless areas. The understory vegetation is dominated by a mixture of deciduous shrubs, graminoids, herbs, and mosses. Deciduous shrubs usually include *Vaccinium membranaceum, Menziesia ferruginea*, and *Vaccinium ovalifolium*; graminoids include *Eriophorum angustifolium* and *Carex* spp.; herbs include *Coptis aspleniifolia*, *Cornus canadensis*, *Fauria crista-galli*, *Platanthera dilatata*, and *Rubus pedatus*; mosses include *Pleurozium schreberi*, *Sphagnum girgensohnii*, and *S. capillifolium*.

Figure 3.5.30. Alaska yellow-cedar and mountain hemlock stands (distant and close-up views) on Sphagnum sites bordering non-forested wetland communities of the Eriophorum angustifolium plant order.

HmBa – Foamflower (7) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.7, 3.4.9 to 3.4.11, 3.5.31 and 3.5.32)

Slightly dry to fresh, medium to rich, upper and mid-slopes in the MHmm variant and the mainland portion of the MHwh subzone

Foamflower sites are relatively rare and restricted to water-shedding ridge crests or upper colluvial slopes (commonly below cliffs) that are associated with base-rich soil parent materials, typically limestone. The associated soils include shallow to moderately deep Podzols, rarely Folisols. Forests floors are usually thin and Humimor or Mormoder humus forms dominate. The central edaphic concept (typic site type) is represented by shallow to moderately deep, coarse-skeletal Podzols on intermediate slopes; aberrant site types may include shallow, stony, steep-slope, rocky, organic, and limestone.

Depending on elevation, Foamflower sites support medium- to high-productivity growth of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar. Similarly to Blueberry sites, higher productivity is reflected by the development of closed-canopy, high-density stands, particularly Pacific silver fir stands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Pacific silver fir are most frequent. Western hemlock may be present on steep, warm-aspect slopes at the lower elevation limit of the MHmm variant, while Alaska yellow-cedar is most common on cool-aspect sites. The herb layer is moderately well developed and featues scattered nitrophytic and hygrophytic species, typically *Streptopus roseus*, S. *amplexifolius, Tiarella trifoliata*, and *Veratrum viride*. However, deciduous shrubs and mosses dominate the understory vegetation, especially in high-density stands. The shrub layer includes *Vaccinium membranaceum* and *V. ovalifolium*, and the moss layer includes *Rhytidiadelphus loreus* and *Rhytidiopsis robusta*.
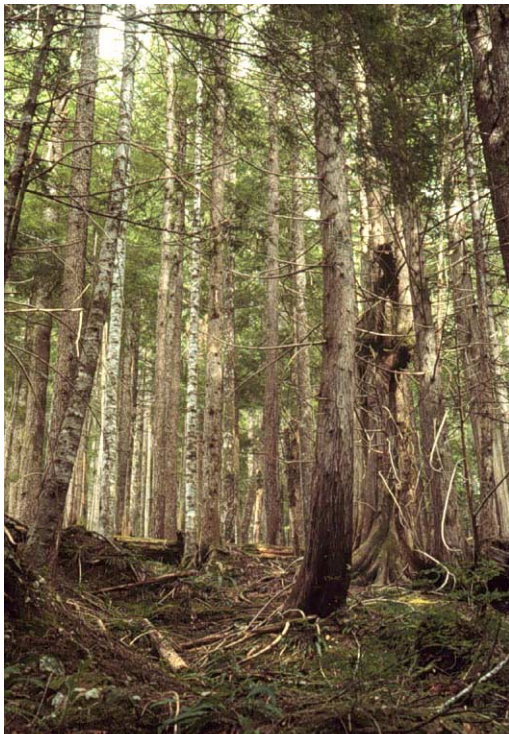

Figure 3.5.31. A dense, mid-seral, Pacific silver fir stand with poorly developed understory vegetation on a Foamflower site.

Figure 3.5.32. An old growth stand of Pacific silver fir and mountain hemlock on a Foamflower site. *Tiarella trifoliata* and *T. laciniata* are scattered in the mossy understory.

HmBl – Valerian (8) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.8 to 3.4.11 and 3.5.33)

Slightly dry to fresh, medium to rich, upper and mid-slopes in the MHms variant

Valerian sites are edaphically analogous to the Foamflower sites, but occur in submaritime climates. They are more frequent than Foamflower sites due to a more frequent occurrence of base-rich soil parent materials and less leached soils on the leeward side of the Coastal Mountains. Valerian sites commonly occupy water-shedding, upper and mid-slopes regardless of aspect. The associated soils include shallow to moderately deep Brunisols, Podzols, or rarely Folisols. Forest floors are usually thin and the Mormoder humus form predominates. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal soils on intermediate slopes; aberrant site types may include shallow, stony, steep-slope, rocky, and limestone.

Depending on elevation, Valerian sites support medium- to high-productivity growth of mountain hemlock, Pacific silver fir, subalpine fir, Engelmann spruce and occasionally, Alaska yellow-cedar. Similarly to Foamflower sites, higher productivity is reflected by the development of closed-canopy, high-density stands, particularly true fir stands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and true firs are most frequent. Western hemlock may be present on steep, warm-aspect slopes at the lower elevation limit of the MHms variant, while Alaska yellow-cedar is most common on cool-aspect sites at the western limit of the variant. The occurrence of Engelmann spruce and subalpine fir increases with increasing continentality and disturbance. The herb layer is well developed, featuring a combination of nitrophytic and hygrophytic species, typically *Gymnocarpium dryopteris, Streptopus roseus, S. amplexifolius, Tiarella trifoliata, Valeriana sitchensis*, and *Veratrum viride*. Deciduous shrubs and mosses are also prominent, especially in high-density stands. The shrub layer includes *Vaccinium membranaceum* and *V. ovalifolium*, and the moss layer includes *Barbilophozia* spp., *Dicranum* spp. and *Rhytidiopsis robusta*. A wide range of species that are common to more continental locations, such as *Arnica latifolia, Ribes lacustre, Sorbus scopulina, Lupinus arcticus, Paxistima myrsinites*, and *Pedicularis bracteosa,* may be present. Similarly, a number of species common on coastal subalpine sites are absent, *e.g., Chamaecyparis nootkatensis*, *Blechnum spicant*, and *Coptis aspleniifolia.*

Figure 3.5.33. Canopy gaps on mid-slope stands on Valerian sites feature a well-developed understory.

HmSs – Reedgrass (9) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.6, 3.4.9 to 3.4.11 and 3.5.34)

Slightly dry to fresh, medium to rich, upper and mid-slopes in the MHwh subzone

Reedgrass sites are restricted to the hypermaritime climates of the western coast of Vancouver Island, the Central Coast, and the Queen Charlotte Islands. Their occurrence increases with the increasing influence of hypermaritime climates, and they are most abundant on the Queen Charlotte Islands. They are typically found on steep, water-shedding, upper and mid-slopes on base-rich morainal or colluvial materials. The associated soils include shallow to moderately deep Podzols, rarely Folisols. Forests floors are usually thin and Humimor or Mormoder humus forms predominate. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Podzols on intermediate slopes; aberrant site types include shallow, stony, steep-slope, rocky, limestone, and organic.

Depending on elevation, Reedgrass sites support low- to medium-productivity growth of mountain hemlock, western hemlock, Sitka spruce, and Alaska yellow-cedar. Higher productivity is reflected by the development of closed-canopy stands with a high basal area, particularly hemlock and/or Sitka spruce stands. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Alaska yellow-cedar are most frequent. The understory vegetation consists of a mixture of deciduous shrubs, graminoids, herbs, and bryophytes, which dominate the life form spectrum. The shrub layer includes *Vaccinium ovalifolium* and *V. parvifolium*; the herb layer includes *Blechnum spicant, Calamgrostis nutkaensis, Coptis aspleniifolia, Cornus canadensis, Huperzia selago, Streptopus roseus, Tiarella trifoliata*, and *Veratrum viride*; the moss layer includes *Hylocomium splendens, Plagiothecium undulatum, Rhizomnium glabrescens, Rhytidiadelphus loreus, Pellia neesiana*, and *Scapania bolanderi*.

Figure 3.5.34. An open-canopy stand of mountain hemlock and Alaska yellow-cedar with a well developed mossy understory on a mid-slope Reedgrass site (Queen Charlotte Islands, photo: J. Pojar).

HmYc – Twistedstalk (10) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.6, 3.4.9, to 3.4.11and 3.5.35)

Moist, medium to rich, on water-receiving mid-slopes in the MHwh subzone

Twistedstalk sites represent a floristically similar, but wetter, analog to Reedgrass sites. They are restricted to the hypermaritime climates of the western coast of Vancouver Island, the Central Coast, and the Queen Charlotte Islands. These sites become more common with the increasing influence of hypermaritime climates, and they are most abundant in the Queen Charlotte Islands. Twistedstalk sites are typically found on water-receiving mid- and lower slopes associated with base-rich morainal or colluvial materials. The associated soils include shallow to moderately deep gleyed Podzols, Gleysols, rarely Humisols, with Hydromoder humus forms. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Gleyed Podzols; aberrant site types include shallow, steep-slope, gleysolic, and organic.

Depending on elevation, Twistedstalk sites support low- and, less often, medium-productivity growth of mountain hemlock, western hemlock, Sitka spruce, and Alaska yellow-cedar. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock and Alaska yellow-cedar are most frequent. Similar to Reedgrass sites, the understory vegetation consists of a mixture of deciduous shrubs, graminoids, herbs, and bryophytes; however hygrophytic and hydrophytic species, such as *Blechnum spicant, Coptis aspleniifolia, Streptopus roseus, Tiarella trifoliata*, and *Veratrum viride*, occur more frequently and abundantly.
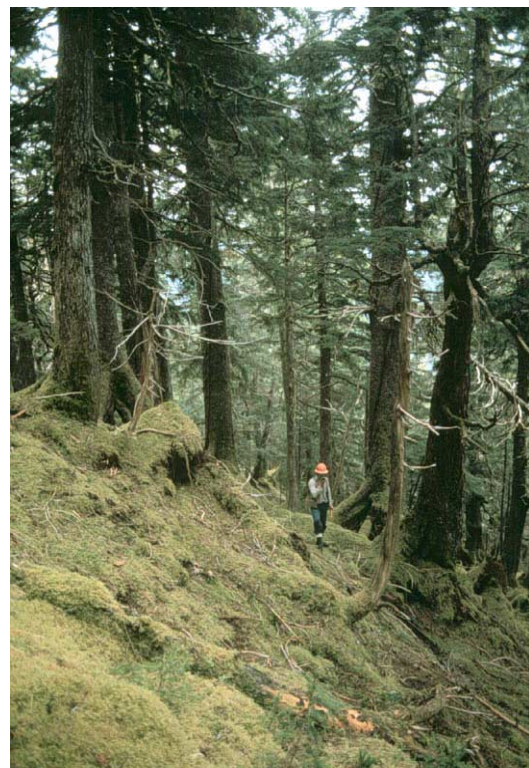

Figure 3.5.35. Open-canopy stands of mountain hemlock and Alaska yellow-cedar with scattered Sitka spruce on mid- and lower-slope Twistedstalk sites.

HmBa – Lady Fern (11) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.7, 3.4.9 to 3.4.11 and 3.5.36)

Moist to very moist, medium to rich (very rich), water-receiving, mid- and lower slopes in the MHmm variant and the mainland portion of the MHwh subzone

Lady Fern sites occupy water-receiving slopes that associated with permanent, or at least prolonged, seepage or inherently rich soils. The associated soils are moderately deep to deep soils with thick humus layers. The abundant moisture from precipitation and seepage results in varying degrees of gleying. Soils include gleyed Humic Podzols, Humisols, Brunisols, and Gleysols, usually without a well-defined Ae horizon. Humus forms are typically Hydromoders. The central edaphic concept (typic site type) is represented by moderately deep, coarse-skeletal Podzols on intermediate slopes; aberrant site types may include shallow, stony, steep-slope, rocky, organic, and limestone.

Depending on elevation and soil moisture conditions, Lady Fern sites support high-productivity growth of mountain hemlock, Pacific silver fir, and Alaka yellow-cedar (Brooke *et al.* 1970). Similarly to Foamflower sites, higher productivity is reflected by the development of closed-canopy stands with a high basal area, particularly Pacific silver fir stands. Any of these species may dominate the tree layer, but nearly pure stands of Pacific silver fir are most frequent. Alaska yellow-cedar is most common on cool-aspect sites at the upper elevation limit of the MHmm variant. The shrub, herb, and moss layers are well developed, and the frequency of both hygrophytic and nitrophytic species is >20%. In addition to mesophytic ericaceous shrubs (*Menziesia ferruginea, Vaccinium membranaceum*, and *V. ovalifolium*), the shrub layer includes *Oplopanax horridus* and *Rubus spectabilis*. The diverse herb layer features *Athyrium filix-femina*, *Blechnum spicant*, *Clintonia uniflora, Gymnocarpium dryopteris, Rubus pedatus, Streptopus roseus*, *S. amplexifolius, Tiarella trifoliata, Valeriana sitchensis*, and *Veratrum viride. Rhytidiadelphus loreus, Rhytidiopsis robusta*, and *Rhizomnium nudum* inhabit the moss layer. The change in soil nutrient conditions from medium to very rich is manifested by decreasing cover of oxylophytic species (ericaceous shrubs) and increasing presence and cover of nitrophytic species, particularly *Athyrium filix-femina* and *Tiarella trifoliata*.

Figure 3.5.36. Pacific silver fir often forms pure, closed-canopy, high productivity stands on moist Lady Fern sites.

HmBl – Lady Fern (12) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.8 to 3.4.11, and 3.5.37)

Moist to very moist, medium to rich (very rich), water-receiving, mid- and lower slopes in the MHms variant

Submaritime Lady Fern sites are edaphically analogous to the maritime Lady Fern sites. They are quite common at the upper elevation limit of the MHms variant and in the Coast-Interior transition represented ecologically by the transition between the MH and the ESSF zones. Submaritime Lady Fern communities may extend into the lower parkland subzone as tree islands or open-canopy stands on water-receiving slopes with permanent, or at least prolonged, seepage or inherently rich soils. The associated soils are moderately deep to deep gleyed Brunisols, Podzols, and Gleysols, with relatively thin Mormoder, Moder, Mullmoder, or Mull humus forms. The central edaphic concept (typic site type) is represented by moderately deep, medium-textured soils on intermediate slopes; aberrant site types may include shallow, stony, steep-slope, rocky, and organic.

Depending on elevation and soil moisture conditions, Lady Fern sites have the potential to support high-productivity growth of Pacific silver fir, subalpine fir, and Engelmann spruce. The occurrence of Engelmann spruce and subalpine fir increases, and that of Alaska yellow-cedar decreases, with increasing continentality. Any of these species may dominate the tree layer, but mixed-species stands of mountain hemlock, Pacific silver fir and subalpine fir are most frequent. Mountain hemlock, Pacific silver fir, and Alaska yellow-cedar are the most common tree species on cool-aspect, high snowpack sites. The forest canopy is usually semi-open, allowing for the vigourous development of understory vegetation. The shrub, herb, and moss layers are well-developed, and the frequency of both hygrophytic and nitrophytic species is >20%. In addition to mesophytic ericaceous shrubs (*Menziesia ferruginea, Vaccinium membranaceum*, and *V. ovalifolium*), the shrub layer includes *Oplopanax horridus* and *Rubus spectabilis*. The diverse herb layer features *Athyrium filix-femina, Clintonia uniflora, Gymnocarpium dryopteris, Mitella pentandra, Rubus pedatus, Streptopus roseus, S. amplexifolius, Tiarella trifoliata, Valeriana sitchensis*, and *Veratrum viride. Rhytidiopsis robusta* and *Rhizomnium glabrescens* are most frequent in the moss layer. The change in soil nutrient conditions from medium to very rich is manifested by decreasing cover of oxylophytic species (ericaceous shrubs) and increasing presence and cover nitrophytic species, particularly *Athyrium filix-femina*, *Tiarella trifoliata*, and *Valeriana sitchensis*.

Figure 3.5.37. Well-developed herbaceous understories (shrub-dominated (left) and herb and fern-dominated (right) in old-growth subalpine fir, Pacific silver fir and Englemann spruce Lady Fern sites in the MHms variant.

HmYc – Marsh-Marigold (13) site association

(References: Table 3.4.2; Figures 3.4.5, 3.4.6, 3.4.9 to 3.4.11, and 3.5.38)

Very moist, medium to rich (rarely very rich), water-receiving mid- and lower slopes in the MHwh subzone

Marsh-Marigold sites represent an edaphically richer analog to Deer-Cabbage sites. These sites are restricted to the hypermaritime climates of the western coast of Vancouver Island, the Central Coast, and the Queen Charlotte Islands.Their occurrence increases with the increasing influence of hypermaritime climate, and they are most abundant in the Queen Charlotte Islands. Marsh-Marigold sites occupy water-receiving lower slopes with permanent seepage. The associated soils are derived from colluvial, morainal, or organic materials, and include Gleysols (occasionally Humisols); with thick Hydromor or Hydromoder humus forms. The central edaphic concept (typic site type) is represented by Humic Gleysols on gentle slopes; aberrant site types include shallow, sloped, and organic.

Marsh-Marigold sites support very low- to low-productivity growth of mountain hemlock, western hemlock, Sitka spruce, western redcedar, and Alaska yellow-cedar. Open-canopy, multi-storied, clumpy, often scrubby, mixed-species stands of hemlock and cedars are most frequent. The understory vegetation consists of a mixture of 'low'- and 'high'-elevation deciduous shrubs, herbs, and bryophytes; however hygrophytic and hydrophytic species occur more frequently and with a higher abundance than on the drier Twistedstalk sites. The shrub layer includes *Gaultheria shallon*, *Menziesia ferruginea, Vaccinium parvifolium*, and *V. ovalifolium*. The herb layer is species-diverse featuring the diagnostic *Caltha leptosepala*, *Coptis aspleniifolia*, *Blechnum spicant*, *Cornus canadensis*, *Hyperzia selago, Lycopodium clavatum, Listera* spp., *Lysichiton americanum*, *Maianthemum dilatatum*, *Rubus pedatus*, *Streptopus roseus*, and *Veratrum viride*. The moss layer is also species-rich, with a high presence and cover of *Plagiothecium undulatum, Hylocomium splendens*, *Rhytidiadelphus loreus*, *Scapania bolanderi*, *Rhizomnium glabrescens, Sphagnum girgensohnii*, and *Mylia taylori*.

Figure 3.5.38. A semi-open canopy stand of mountain hemlock and Alaska yellow-cedar on a lower-slope Marsh-Marigold site.

HmYc – Skunk Cabbage (14) site association

(References: Table 3.4.2; Figures 3.4.5 to 3.4.11, and 3.5.39)

Wet, medium to ich (rarely very rich), water-collecting sites in forested subzones

Skunk Cabbage sites support the development of forested communities throughout the forested subzones. Their occurrence decreases with increasing elevation and increasing continentality. With decreasing elevation, mountain hemlock and Alaska yellow-cedar are replaced by western hemlock and western redcedar. With increasing elevation, Skunk Cabbage communities are ultimately replaced by high-elevation, non-forested wetland communities of the Carex pluriflora, Eriophorum angustifolium, and Carex nigricans plant orders. These swamp-like sites occupy flats or depressions, but may occur on toe or lower slopes, where they are associated with springs. As a result, Skunk Cabbage sites have poor drainage and deficient aeration, and may have a higher snowpack and longer snow duration than upland sites. Trees and deciduous shrubs inhabit drier elevation prominences, while herbs and bryophytes inhabit wetter, treeless microsites. The associated soils are usually a complex of Gleyed Podzols, Gleysols, Mesisols, and Humisols, typically with Hydromoder or Saprimoder humus forms. The central edaphic concept (typic site type) is represented by Humic Gleysols; the aberrant types are slope and organic.

Skunk Cabbage sites have a very low to low productivity and tree growth is often scrubby. Tree species include mountain hemlock and Alaska yellow-cedar, to a lesser extent Pacific silver fir (maritime climates) and subalpine fir (submaritime climates). Consequenly they are unsuitable (slope and organic types), or marginally suitable on typic sites for timber production. Groundwater moves slowly through the soil, often stagnating in depressions and forming small pools. The depth of the groundwater table and its movement control the amount of dissolved oxygen and are the major determinants of productivity. The microtopography, and hence the vegetation, of Skunk Cabbage sites displays a distinct mound-depression pattern. The discontinuous forest canopy and random-group distribution pattern of trees and understory plants is due to the presence of surface water, which inhibits the establishment of terrestrial vegetation, and to windthrow. Regeneration and productive growth of trees is confined to drier, raised organic mounds, which originated from uprooted trees. These microsites are usually inhabited by the oxylophytic plants characteristic of Blueberry sites. In the shrub layer this mound-depression pattern is manifested by the presence of *Vaccinium ovalifolium* and *Rubus spectabilis*, in the herb layer by *Rubus pedatus* and *Lysichiton americanum*, and in the moss layer by *Rhytidiadelphus loreus* and *Rhizomnium glabrescens* and *Sphagnum girgensohnii*. The understory vegetation is well-developed, particularly the shrub, herb, and moss layers. Dominant species include *Athyrium filix-femina*, *Fauria crista-galli* (upper elevations), *Vaccinium ovalifolium*, *Rhizomnium glabrescens*, *Sphagnum girgensohnii*, and *Lysichiton americanum*.

Figure 3.5.39. Open-canopy, low productivity, Alaska yellow-cedar-dominated stands on wet, medium Skunk Cabbage sites in the lower forested MH subzones.

4 VEGETATION–ENVIRONMENT RELATIONSHIPS

4.1 STAND STRUCTURE AND FOREST DYNAMICS

This section is based on Klinka et al.1992.

The coastal subalpine forest consists of a variable, albeit not very species-diverse, pattern of old-growth forest stands. The scarcity of extensive, young, even-aged stands is conspicuous and suggests that large-scale disturbances rarely occur. Stand structure varies with location and site characteristics. The most important include: climate, snowpack duration, continentality, topography (*e.g.*, slope aspect and gradient), soil moisture and nutrient conditions, stand age, and disturbance history.

The associates of mountain hemlock (the major climatic climax species of the MH zone) are Pacific silver fir and Alaska yellow-cedar. There appear to be no prominent shade-intolerant tree species that could be designated pioneer or early-seral species. Information on the silvics of these species is given in Krajina (1969), Klinka *et al.* (2000), Burns and Honkala (1990), and in the bibliographies for mountain hemlock by Franklin (1962), for Pacific silver fir by Williams and Franklin (1965), and for Alaska yellow-cedar by Harris (1969).

There is no stand-specific information on the age of old-growth stands. Stand age appears to range from 200 to 500 years, with Alaska yellow-cedar trees older than 1,000 years on some sites. The recent study of Lertzman (1989) suggests that the lifespan of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar in the MH zone is considerably higher than their maximum ages reported in literature (*e.g.*, Heinselman 1981; Vogt *et al.* 1989). Advance regeneration of Pacific silver fir can still release after more than 200 years.

Several trends are apparent in the distribution and form of trees and in the occurrence and vigour of advance regeneration along an elevation/snowpack gradient. Specifically, with increasing depth and duration of snowpack:

1. trees are increasingly confined to elevated microsites (usually raised organic mounds);
2. the occurrence of non-forested (bryophyte, sedge, herb, and shrub) communities increases along spring-lines and seepage-lines, in depressions, flush habitats and on flats increases;
3. the frequency of trees with butt sweep increases; and
4. the abundance and vigour of advance regeneration decreases.

These trends indicate that:

1. on some sites full occupancy by trees is not possible;
2. successful tree establishment and growth requires special microsites;
3. the shade tolerance of mountain hemlock, Pacific silver fir and Alaska yellow-cedar may decrease with increasing snowpack (Krajina 1969; Scott *et al.* 1976); and
4. regeneration (either natural or planted) after clearcutting at the upper limit of the forested subzones may not be feasible (Klinka and Pendl 1976), because although regeneration is physiologically possible, young trees need protection from the very deep and heavy snowpack.

At the upper elevation limits of the forested subzones only elevated microsites support the growth of clusters (clumps) of 2 or more large trees. Each cluster is surrounded at the perimeter by advance regeneration and/or ericaceous shrubs, and the space between the clusters (usually depressions) is typically occupied by bryophytes as the growth of trees and shrubs is hindered by deep snow. This tree distribution pattern, which is most obvious in the parkland subzones, means that the trees experience a growing season that is 3 to 6 weeks longer than that in the depressions (Brooke *et al.* 1970). The presence of decaying stumps and short snags within the clusters indicate that little change in pattern has occurred over time and that the tree clusters are self-perpetuating in a successional context (see Section).

Many, but not all, subalpine old-growth stands have closed canopies and full stocking, giving the impression of uniform, single-cohort stands, and are in an advanced stage of understory reinitiation (Oliver and Larson 1990). Typically, the tree layer appears to have approximately the same height and diameter distribution characteristics of even-aged stands, with little or no recruits in the lower tree and upper shrub layers but abundant recruits in the lower shrub and/or herb layers. This does not mean that the stands are truly even-aged considering criteria used for low-elevation stands (*e.g.*, Smith 1986). These stands are quite old (>300 years), can be dominated by mountain hemlock (Figure 4.1.1), a combination of mountain hemlock and Alaska yellow-cedar (Figure 4.1.1), or Pacific silver fir (Figure 4.1.2) and they usually have an understory dominated predominantly by bryophytes with scattered *Vaccinium* spp.
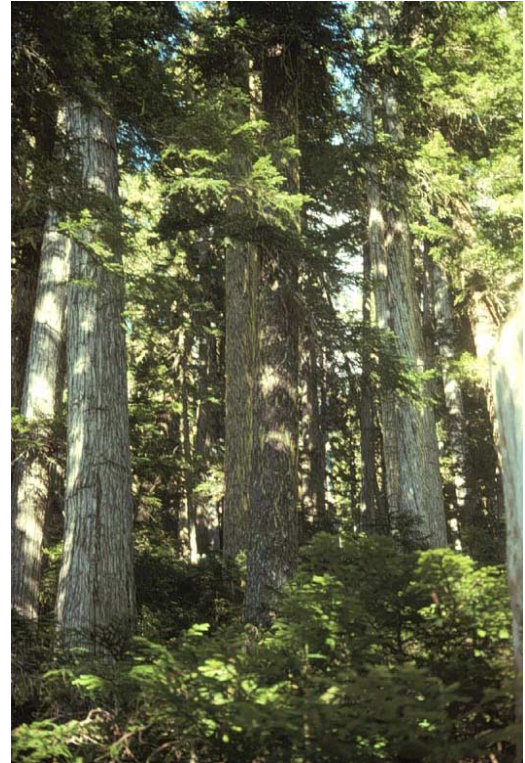
Figure 4.1.1. Uniform, single-storied old-growth stands dominated by mountain hemlock (left) and a mixture of mountain hemlock and Alaska yellow-cedar (right) that are likely uneven-aged.

Figure 4.1.2. Uniform, single-storied old-growth stands of Pacific silver fir with mountain hemlock that are probably uneven-aged.

It is known that surviving advance regeneration of mountain hemlock, Pacific silver fir and Alaska yellow-cedar can be over 100 years old and that the trees of similar size can be of very different ages (Herring and Etheridge 1976; Klinka *et al.* 1992). It is also known that seeding, germination and growth of advance regeneration may extend over a considerable period of time (Herring and Etheridge 1976). Therefore, the criterion of a very narrow age range for even-aged stands is not applicable to coastal subalpine forest where the age at release ('effective age'), or use of a greater age range, would be more meaningful than establishment age. The term single-cohort is more appropriate than even-aged for describing the structure of these stands.

In addition to these types of stands, there exist truly uneven-aged, multi-cohort (Oliver and Larson 1990) stands that seem to display a reverse J-shaped height and diameter class distribution with a great range in the age and size of trees. Such stands occur more frequently on the windward (wetter and more maritime) side than on the leeward (drier and less maritime) side of the Vancouver Island Mountains and Pacific Ranges. Three structural types are recognized: (1) 'exposed-ridge', (2) 'wind-contracted' and (3) 'climax'.

The stands in all three types appear to be self-perpetuating via regeneration in small gaps and/or larger patches created by windthrow or mortality in the tree layer. Causes of individual tree mortality are not well known. The high longevity of subalpine stands implies that there are few losses to disease, insects, and pathogens. Occasional absence of Pacific silver fir may be due to its shorter lifespan compared to mountain hemlock and Alaska yellow-cedar, or possibly periodic mortality caused by the balsam woolly aphid. Tree tops of all three structural types in the coastal subalpine forests are commonly deformed as a result of damage from snow loads or ice.

'Exposed-ridge' stands usually have shallow and discontinuous soils and manifest a history of continuous regeneration in windthrow gaps. Dominant trees often have deep live crowns suggesting that the stands were never fully or densely stocked. These stands are uneven-aged, and structurally (in terms of height and diameter) they may be either uniform (even-sized), resembling single-storied, even-aged stands, or balanced multi-storied stands, with an inverse-J distribution of size or age classes (Smith 1986); often with a well-developed *Vaccinium* spp. understory (Figure 4.1.3).

Figure 4.1.3. An exposed-ridge old-growth stand of mountain hemlock and Alaska yellow-cedar in the MHmm-s subzone.

Stands displaying the 'wind-contracted' and 'climax' structures appear to have been undisturbed by fire or a large-scale windthrow for at least 1,000 years, and both have a considerable component of Alaska yellow-cedar. The 'wind-contracted' type is probably restricted to the outer coast of Vancouver Island, and is characterized by broken-off tops and large branches in all trees with very large diameters.

Stands displaying the 'climax' structure, also more prevalent on the windward than on the leeward side and on protected moist (Moist Blueberry and Deer-Cabbage) sites, have the following characteristics:

1. a semi-open canopy;
2. continuous ingress of trees into gaps;
3. a preponderance of live and dead, usually multitopped Alaska yellow-cedar;
4. an understory dominated by ericaceous shrubs (*e.g.*, *Cladothamnus pyroliflorus, Menziesia ferruginea, Phyllodoce empetriformis, Vaccinium alaskaense, V. membranaceum, V. ovalifolium,* and *Rhododendron albiflorum*) and oxylophytic (*i.e.* species that prefer acidic soils) bryophytes and lichens (*e.g.*, *Cetraria sten-ophylla, Cladonia bellidiflora, C. conicraea, C. gracilis, C. squamosa, Dicranum scoparium, Hylocomium splendens, Pleurozium schreberi,* and *Rhytidiopsis robusta*); and
5. compacted, very thick (30 to >100 cm), poorly aerated and extremely acid forest floors (pH 2.9 to 3.5) composed mostly (>50%) of ligneous materials, mainly roots and decaying wood (Resimor and Lignomor humus forms).

As stands develop from the even-sized stage through a transitional stage (Figure 4.1.4) into a true old-growth stage (Figure 4.1.5), they become less productive. The true old-growth (climax) stage represents a situation in which forest growth is severely constrained by nutrient limitations. Nutrients are immobilized either in the tree biomass (*e.g.*, Matson and Boone 1985) and/or the forest floor (*e.g.*, Krause *et al.* 1978; Klinka *et al.* 1990a). Thus, climax ecosystems in this zone may be considered naturally less efficient and productive than at earlier successional stages. Disturbance, either by wind or fire, is considered to be an important mechanism for the natural revitalization of these ecosystems (Ugolini and Mann 1979; Lewis 1982, 1985; Ugolini 1982; Weetman *et al.* 1989a,b; Messier and Kimmins 1990; Weetman *et al.* 1990).
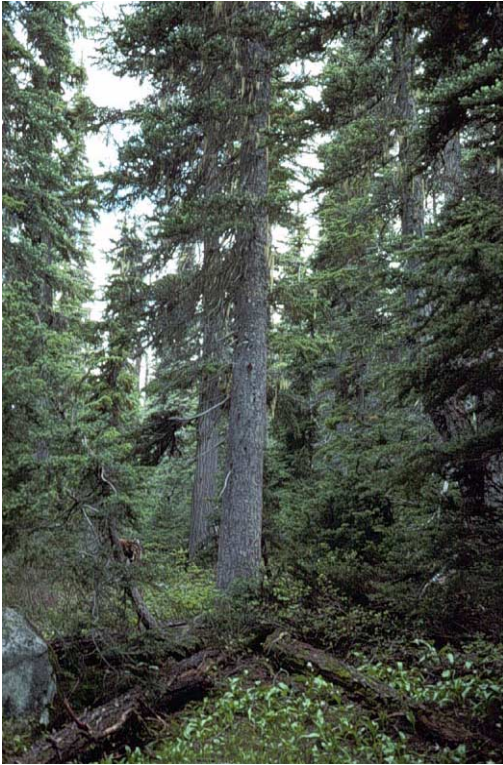
Figure 4.1.4. Uneven-aged stand of Pacific silver fir and mountain hemlock in the transition stage between the even-sized old-growth and the true climax (MHms variant).

Figure 4.1.5. True old-growth ('climax') stand dominated by Alaska yellow-cedar (MHms variant).

In the context of secondary succession, it is evident that all old-growth stands were established via natural regeneration, regardless of the disturbance type. This occurred either by the release of advance regeneration from overstory suppression (in gaps following individual or group mortality or disturbance of old trees, or by seeding from trees remaining after a disturbance.

Based on the presence of charcoal deep in the forest floor, the presence of living or dead western white pines, and fire scars on Alaska yellow-cedar, some 'uniform, even-sized' stands probably developed after fires 200 or more years ago. In other stands downed trees are present on and in the forest floor, suggesting stand-originating windthrow events. The signs of both types of disturbance are clearly evident in a few existing young stands (50 to 150 years old).

Brooke *et al.* (1970) found traces and fragments of charcoal in approximately one-third of the 140 soil pits studied. They considered charcoal fragments below the forest floor to be evidence of past fires *in situ*, and suggested that fires may have occurred in the early 1600s and in the late 1700s. Large fragments of charcoal deeply incorporated into the mineral soil were interpreted as the remains of roots burned in high severity fires.

On the basis of observations and local studies (Brooke *et al.* 1970; Lertzman 1989), these two major disturbance types initiate different successional pathways leading to the climax stage:

1. Windthrow results in the development of mountain hemlock/Pacific silver fir mixtures, with Pacific silver fir often dominating (Figure 4.1.6). If undisturbed, there may be several cycles with alternating dominance of either species accompanied by increasing stand fragmentation, heterogeneity in stand structure and increasing role of Alaska yellow-cedar, before reaching the climax stage.

Figure 4.1.6. Pacific silver fir-dominated stands in the stem exclusion stage that regenerated naturally following windthrow.

2. Fire results in the development of mountain hemlock/Alaska yellow-cedar mixtures, with either species dominating. The abundance of Pacific silver fir depends on the extent to which its advance regeneration has been spared by fire (Figure 4.1.7). Both mountain hemlock and Alaska yellow-cedar have light seeds and regenerate better on burned forest floor and exposed mineral soil than Pacific silver fir. If undisturbed, there may again be several cycles with alternating dominance of either species accompanied by increasing stand fragmentation, heterogeneity in stand structure, and perhaps some infiltration of Pacific silver fir before reaching the climax stage.

Figure 4.1.7. Mountain hemlock-dominated stands in the understory reinitiation stage of stand development. Based on the presence of charcoal in forest floors and the predominance of mountain hemlock, these stands are suspected to have regenerated after fire.

Summary

The coastal subalpine forest can be considered virgin, old, or of ancient age (pre-climax and climax). It is rare compared to other coniferous forest types of the world, and virtually unique to British Columbia. Compared to the low-elevation forest, this forest has been infrequently disturbed (cycles of 200 years or more), and there are few losses to insects or disease, allowing the trees to live to great ages. The silvics of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar are not well known and the dynamics and site-specific successional pathways of the forest have not been documented. The forest appears to be resilient although its recovery from disturbance is very slow.

4.2 THE INFLUENCE OF SNOW

This section is based in part on Brooke et al. 1970, and in part on Klinka et al. 1992.

Large quantities of snow accumulate annually in the MH zone (Figure 4.2.1) and its influence is reflected by the vegetation. This influence is expressed by a break in the distribution of epiphytic lichens on tree trunks at the winter snowline, breakage and deformation of shrubs, saplings, and trees, and the control of small- and large-scale vegetation patterns through distribution and duration of the snowpack (see Section 3.2 ZONAL CLASSIFICATION on page 14 - Zonation and Climatic Localisms on page 26).

The position of the lichens *Alectoria sarmentosa* and *Sphaerophorus globosus* marks the winter snowline on mountain hemlock and Pacific silver fir trunks (Figure 4.2.2). This position gradually shifts upward along the tree trunks with increasing elevation and snow depth.
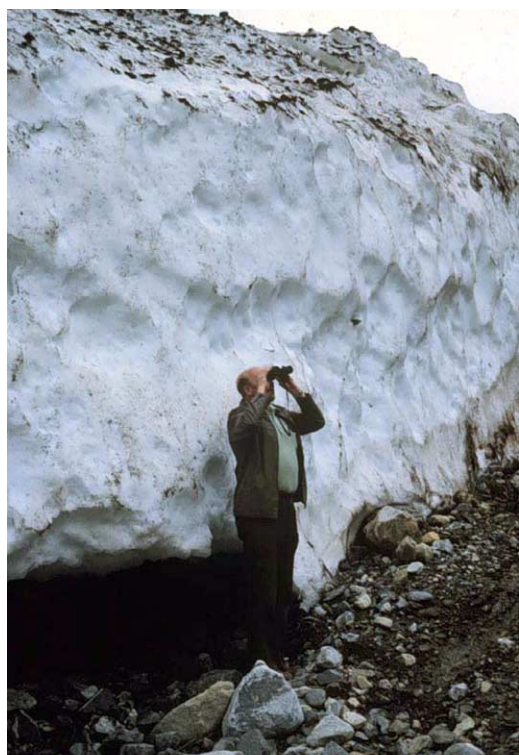
Figure 4.2.1. The snowpack in the MH forest can be enormous at times.

Figure 4.2.2. The height of epiphytic lichens marks the average depth of winter snowpack.

The snowpack exerts a strong downward force. Seedlings are bent and depressed annually by the snow load, which can sometimes exceed 950 kg per tree. Seedlings surrounding isolated trees or tree clumps on flat terrain receive additional snow that cascades from the crowns of the larger neighbouring trees. All mountain hemlock, Pacific silver fir, and Alaska yellow-cedar show mechanical damage from the snowpack. Species with flexible stems and branches (Alaska yellow-cedar, and, to a lesser degree, mountain hemlock) are more resilient. While they exhibit the greatest deformation, they have higher rates of recovery and will often return to a more or less upright position following snowmelt (Figure 4.2.3). Pacific silver fir has a low resistance to bending before failure and breakage occur (Figure 4.2.4) (Burns and Honkala 1990).

Figure 4.2.3. These resilient Alaska yellow-cedar saplings will likely return to an upright position after snowmelt.

Figure 4.2.4. Irrecoverable terminal leader breakage on a sub-canopy Pacific silver fir sapling, which has resumed lateral, but not apical growth.

Mountain Hemlock Zone

Movement of snow may reach a maximum rate of 15 cm per week on steeper slopes, and may have enough pressure to push loose stones and boulders. When trees are above the maximum winter snowpack, the upper stems may remain upright, but a distinct basal butt sweep or snowcrook remains as evidence of the great force of snowcreep (Figures 4.2.5 and 4.2.6). Successive freeze-thaw cycles can result in the formation of ice lenses which, when compressed, result in a particularly destructive vertical force.

Figure 4.2.5. Butt sweeps caused by snow creep.

Figure 4.2.6. These saplings will develop butt sweeps.

On high snowpack sites, successful regeneration will require protection from the great depth and long duration of the snowpack (Figure 4.2.7). This protection can be provided by shelterwood cuttings (providing temporary protection) or selection cuttings (providing prolonged protection) (see Section 5.7 Reproduction Cutting Options on page 158).
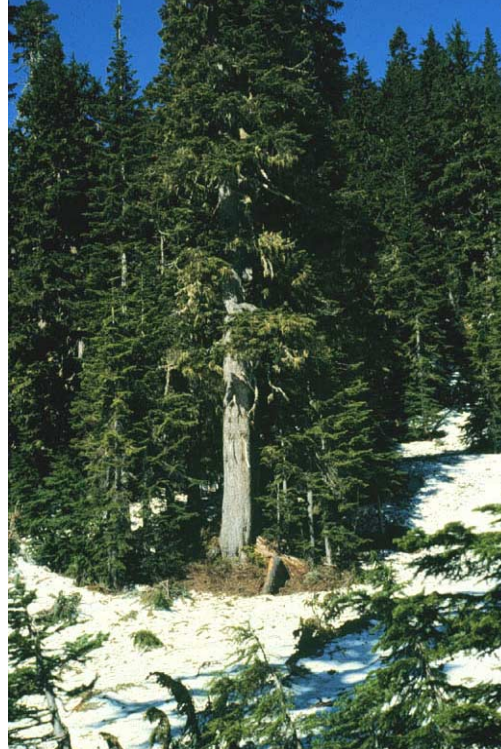
Figure 4.2.7. The absence of advance regeneration outside of the tree island demonstrates the requirement for protection.

Summary

The duration and depth of the winter snowpack have a profound influence on vegetation in the coastal subalpine forest and must be considered when making tree species and reproduction cutting decisions. The three major tree species of this zone are mountain hemlock, Pacific silver fir, and Alaska yellow-cedar. While all three exhibit damage from the heavy snow loads, stem and branch flexibility contribute to resilience and recovery to upright form. The species, in order of decreasing flexibility: Alaska yellow-cedar, mountain hemlock, Pacific silver fir. Pacific silver fir often suffers from damage and failure due to snow loading as it is relatively inflexible.

4.3 REGENERATION PATTERNS

This section is based on Brett (1997b).

Regeneration patterns in the coastal forest change with elevation. At lower elevations within the CWH zone, regeneration matches the gap model: trees are most likely to regenerate in gaps in the forest canopy caused by the death of one or more trees (Figures 4.3.1 and 4.3.2). While under the gap model regeneration is favoured far from other trees, the deep snowpack at high elevation inverts the pattern to favour regeneration close to other trees, resulting in tree islands which define the parkland MH subzones (the tree-island model, Figures Figures 4.3.3 and 4.3.4). Tree islands are usually on raised ridges or mounds that are first to emerge from snow and are the only microsites with a growing season long enough to support tree establishment and survival. Regeneration patterns within the forested MH subzones are intermediate between these two models.
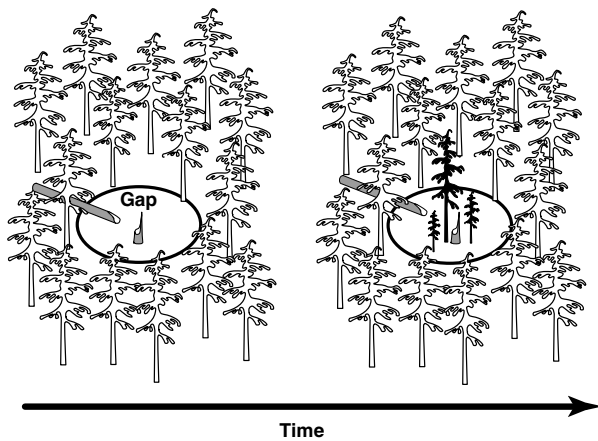
Figure 4.3.1. The gap model: a canopy gap is formed by the death of one or more canopy trees and with the passage of time, a new canopy tree eventually fills the gap. A tree is most likely to reach the canopy layer far from other trees.

Figure 4.3.2. Natural regeneration in a canopy gap (montane forest).
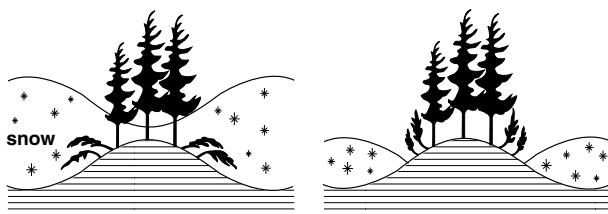
Figure 4.3.3. The tree-island model: with the onset of warmer weather, snow melts first near the trees and on mounds. Trees are most likely to establish and survive close to other trees.

Figure 4.3.4. Natural regeneration surrounding a tree island.

Stands on late-snowmelt sites have a more open canopy than stands on early-snowmelt sites. Late-snowmelt sites are more likely to be north-facing or flat than south-facing and steep. Most trees die singly and remain standing, thus there are no large canopy openings created by multiple treefalls as are common in low-elevation stands. Although there are many large (up to 600 m²) late-snowmelt gaps, especially on flat sites, they do not support the ingress of trees that could be expected if such gaps were required for regeneration. Most late-snowmelt gaps show no evidence of ever having supported canopy trees, *i.e.*, stumps are rare. In addition, most regeneration is usually <2 m tall and buried by snow well into June: thus it is unlikely that these gaps have the potential to support canopy trees in the near future.

On mounds, under the forest canopy and close to canopy trees there is less snow accumulation and earlier snowmelt (Figure 4.3.5). Distinct snow craters form around tree boles, which reradiate incident radiation (Figure 4.3.6). Regeneration is most successful on these microsites with shorter snow duration and does not appear to be affected by the overhead canopy, apparently because of low-angle diffuse light. In contrast to most forested ecosystems, seedlings establish on undisturbed forest floor rather than on decaying wood or mineral soil and almost all surviving seedlings are growing on this substrate (Figure 4.3.7).

Figure 4.3.5. Snow melts earlier under the forest canopy and on mounds in the forested MH subzones.

Figure 4.3.6. Snow craters form around tree boles in the upper MH parkland.

Figure 4.3.7. The proportion of regeneration growing on undisturbed forest floor increases with tree height, suggesting regeneration is more likely to survive and grow under a tree canopy.

Mountain Hemlock Zone
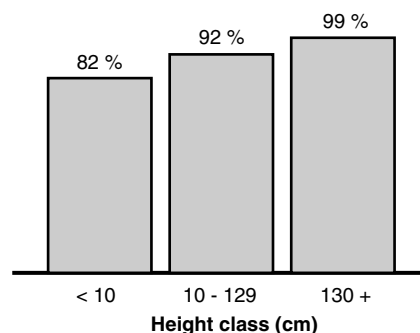
The presence of some regeneration in gaps as well as on mounds and close to canopy trees shows that the forested MH subzones occupy a transition between the gap and tree-island models. The tree-island model is most clearly manifested on flat terrain and on north-facing slopes, which retain snow the longest, and therefore are most similar to upper subalpine sites. It is also more apparent in the regeneration of Alaska yellow-cedar than mountain hemlock. While both species regenerate successfully beside other canopy trees, mountain hemlock is much more common in canopy gaps, especially on steep, south-facing slopes. The different regeneration patterns of these species may be related to their ecological niches. Mountain hemlock is somewhat more exposure-tolerant than Alaska yellow-cedar and is able to grow at higher elevations, often forming the timberline. Therefore, in the parkland subzones snow may more strongly restrict the regeneration of a species near the upper limit of its elevational range (like Alaska yellow-cedar) than of a species in the middle of its range (like mountain hemlock).

Sites that predominantly exhibit the tree-island model of regeneration can be recognized by the following features:

1. snow persists on the ground until late May or longer;
2. regeneration occurs mostly on mounds or close to other trees, particularly when there are distinct tree-islands;
3. a tree species composition that excludes lower-elevation tree species (like western hemlock and Pacific silver fir), especially if subalpine fir is present;
4. open-canopy stands with short (<25 m), heavily-tapered trees and a poorly-developed sub-canopy layer;
5. a predominance of standing dead trees (snags) rather than windthrown trees;
6. treeless gaps without standing water or stumps (late snowmelt gaps);
7. large gaps containing only mountain hemlock and Alaska yellow-cedar understory trees, especially when they are almost prostrate and covered by moss; and
8. presence of plant species that are indicators of upper subalpine sites such as *Cassiope* and *Phyllodoce* spp., *Empetrum nigrum*, *Luetkea pectinata*, and *Rhododendron albiflorum*.

Summary

Understanding and recognizing regeneration patterns in the MH zone (the gap model, the tree-island model, and their transition) is important for making decisions regarding reproduction cutting and tree species selection. While the gap model of regeneration indicates relatively few potential regeneration problems, the tree-island model of regeneration indicates a high snowpack, severe environmental conditions, and regeneration difficulties. Reproduction methods providing prolonged protection for natural regeneration of Alaska yellow-cedar and mountain hemlock will be most appropriate on sites with a high and long-lasting snowpack; however, it may be prudent to exclude these sites from cutting and timber production considerations.

4.4 FOREST PRODUCTIVITY

This section is based on Klinka et al. 1992.

Understanding how different tree species grow on different sites; how climatic, edaphic and biological factors affect forest productivity; and how long-term forest and site productivity can be sustained is essential for the responsible management of any forest stand under any management objective. Until very recently, this knowledge has been non-existent or very meagre for the coastal subalpine forest. As a result, the standards for regeneration, crown closure, growth & yield and stocking are at best crude approximations that offer no firm grasp of timber management objectives and have little factual basis. There is no data on, or monitoring program for, the early growth of mountain hemlock, Pacific silver fir, or Alaska yellow-cedar on coastal subalpine cutovers. The current growth performance of regeneration and the potential performance of future second-growth stands are unknown. There are no managed stand yield tables for mountain hemlock, Pacific silver fir, or Alaska yellow-cedar (see Section 4.5 Height Growth and Site Index Models for Pacific Silver Fir on page 115). Current practices are limited to short-term management up to the free-growing stage.

The coastal subalpine forest consists of a relatively simple pattern of site associations, each representing a group of ecologically equivalent sites and hence, a certain vegetation and productivity potential. Although site associations are easy to identify, site mapping only commenced recently and therefore the extent of the site associations is not known and they are not yet included in the forest inventory. Until very recently, the productivity potential of each site association has neither been determined nor have relationships between forest productivity and site (see Section 4.7 Forest Productivity - Site Relationships on page 126). Krajina (1969) estimated trends in the variation of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar site index in relation to soil moisture and nutrient availability. He predicted that the highest site indices (at 100 years) for these species were 33 m for mountain hemlock, 33 m for Pacific silver fir, and 30 m for Alaska yellow-cedar.

It is almost impossible to study the growth of uneven-aged old-growth stands composed of trees ranging from 300 to over 1000 years in age, especially when most of the trees have originated from suppressed advance regeneration (30 to 200 years) and possibly have experienced an unknown period of further suppression before being released from shading by the overstory. However, impressive and operable volumes do occur even on low-productivity sites where this volume has accumulated slowly over centuries (Figures 4.4.1 and 4.4.2). Brooke *et al.* (1970) gave a range of 350 to 800 m^3 ha^{-1} in total volume for the North Shore Mountain area. Dynamic processes of mortality and replacement over the past several centuries have given these stands a relatively uniform appearance as volume has accumulated, making productivity estimates difficult and uncertain.

It is evident that climate (temperature, growing season length, and light) and the snowpack exert the dominant influences on forest productivity in the MH zone, but it is recognized that in some situations growth may be severely limited by nutrient availability. Actual evapotranspiration (AET) can be used as an index of potential plant activity. Klinka *et al.* (1979) reported AET values of 465 mm for the CWH zone (the most productive zone in British Columbia), 385 mm for the Coastal Douglas-fir zone, 350 mm for the forested MHmm-s subzone and 270 mm for the MHmm-sp subzone. The AET values calculated by Wang (1993) for the SBS zone, which ranged from 160 to 300 mm, were considerably lower than those for the forested MHmm-s subzone. This suggests that the climatic growth potential in the forested MH subzones is at least equal to that of the montane boreal SBS zone.

Growth performance of regeneration in the MH zone is affected either by poor light in the forest understory and by snowpack in clearcuts (*e.g.*, Krajina 1969; Scott *et al.* 1976; Klinka *et al.* 1992). Better light conditions, such as in canopy gaps, along stand edges, and in the open (clearcuts), result in better height growth of Pacific silver fir (Klinka *et al.* 1992). Potential height growth could therefore be greater than would be predicted by data from old trees (Murray *et al.* 1991). However, the benefit of improved light is probably negated by the greater snowpack in these exposed areas because the full growth potential is not realized until the seedling has grown

well above the snowpack. Thus, improving light conditions may paradoxically increase the depth and duration of the snowpack.
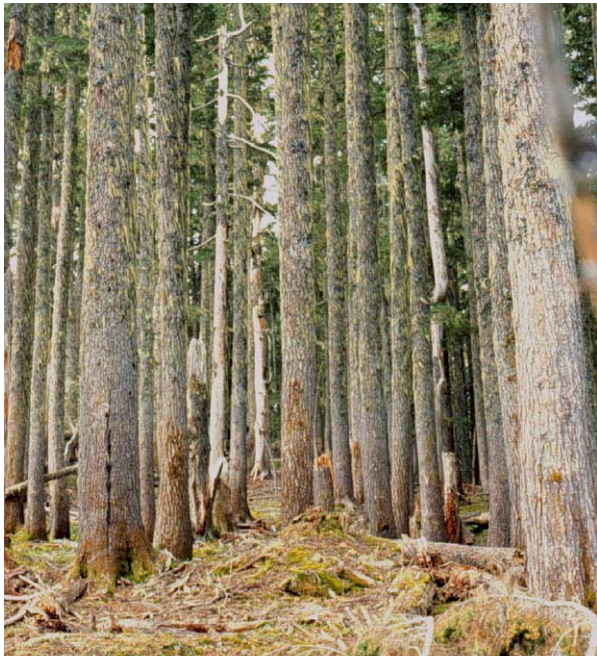
Figure 4.4.1. A high volume mountain hemlock-dominated stand on a fresh and medium site at the lower elevation limit of the MHmm variant.

Figure 4.4.2. A high volume Alaska yellow-cedar dominated stand on a fresh and rich site at the lower elevation limit of the MHmm variant.

At the very least, site-specific height/age curves for each of the major tree species in the MH zone must be developed. To date, this has been done only for Pacific silver fir (see Section 4.5 Height Growth and Site Index Models for Pacific Silver Fir on page 115). The methodology required for development of mixed-species, variable density yield tables should also be a research priority with a careful examination of the opportunities for retrospective studies using existing late-immature stands and stem analysis techniques. Although difficult to locate, sufficiently large even-aged stands of Pacific silver fir that have experienced only marginal suppression can be found. This is also possible for mountain hemlock and Alaska yellow-cedar, but such stands are rare. They could also be used to establish relationships between growth performance and ecological site quality. Furthermore, during the 1990's enough cutovers will have regeneration above breast height to allow the use of the interception technique to estimate site index.

An understanding of forest productivity requires site-specific knowledge of (1) net primary productivity, (2) the effect of extrinsic and intrinsic ecosystem factors on productivity, and (3) the impact of management practices or environmental changes on productivity (*e.g.*, Graham *et al.* 1984; Grier *et al.* 1989; Kimmins 1989; Vogt *et al.* 1989). This will require a systems analysis approach and simulation modelling of productivity and temporal dynamics.

Summary

Due to our limited knowledge of forest/site productivity, planning and decision making in the coastal subalpine forest is fraught with difficulties and uncertainties. As the acquisition of such knowledge will require a considerable period of time, it is necessary to begin gathering site-specific data on the growth performance of regeneration, existing immature stands, and a selected number of old-growth stands in order to establish a baseline for future comparisons. These improved productivity databases are essential for more accurate determination of sustainable yields from this forest type.

4.5 HEIGHT GROWTH AND SITE INDEX MODELS FOR PACIFIC SILVER FIR

This section is based on Splechtna (1999a).

Accurate estimates of site index and height growth trajectories of Pacific silver fir species are needed for yield predictions and for making rational decisions about whether or not to cut stands on marginally productive sites. Height growth curves for Pacific silver fir have been created by Kuruzc (1982), and site index has been estimated from both Kuruzc's (1982) and Hoyer and Hermans' (1989) models. However, Kuruzc's (1982) work was based on low-elevation stands from Vancouver Island, and Hoyer and Herman (1989) used a small data set from the somewhat warmer Washington and Oregon Cascades. The range of Pacific silver fir extends from sea-level to almost timberline, and from the hypermaritime region on the west coast of Vancouver Island to the subcontinental region on the leeward side of the Coast Mountains. In view of this relatively wide climatic amplitude, a large variability in height growth patterns can be expected. Since climate appears to be most strongly related to height growth pattern or the trajectory of height/age curves (Hoyer and Chawes 1980; Milner 1988; Wang *et al.* 1994), the application of existing models to high-elevation or submaritime stands may give biased site index estimates.

In recognition of this climatic variability, climate-specific models were developed and tested against those of Kuruzc (1982) and Hoyer and Herman (1989). The stands in this study were grouped into two continentality strata: (1) maritime and maritime-less maritime (MLM), which includes Vancouver Island and the windward side of the Coastal Mountains and (2) submaritime and subcontinental (SS), which includes the leeward side of the Coast Mountains).

Ninety-eight naturally established, unmanaged stands with the breast height ages of dominant trees over 50 years were sampled. The stands were fully stocked, approximately even-aged, dominated by Pacific silver fir, and located across a wide range of sites throughout the entire native range of the species in southern BC (Table 4.5.1). In each stand, three dominant trees were selected and felled for stem analysis. From the stem analysis data an average curve was calculated for each plot using linear interpolation. From these curves height/age data at 5-year intervals and site index were determined for every plot. Sixty-seven stands were used for calibration, and 31 stands for testing. Since there was a negative correlation between age and site index, a more balanced data set was obtained using only height/age pairs up to 100 years in the calibration data set. However, height/age pairs up to 160 years were used in the test data set.

To predict height growth from site index and breast height age, both a simple conventional polymorphic model based on a conditioned logistic function (Thrower and Goudie 1992; Wang and Klinka 1995; Chen *et al.* 1998), and a climate-specific model (where the MLM and SS continentality strata were used as additional dummy variables) were constructed. Thus, for the climate-specific model, two models were fitted that would allow different curve shapes for different site indices and continentality strata. The performance of the simple polymorphic and the climate-specific models was compared using precision (predicted mean squared error, PMSE) and bias (from residual plots) when predicting height growth of trees in the test data set. The bias of Kurucz's (1982) model was also assessed using a residual plot.

Similarly, simple and climate-specific polymorphic models based on an equation previously used by Carmean and Lenthall (1989) and Thrower and Goudie (1992) were created to predict site index from breast height age and top height. The performance of our models, as well as those by Hoyer and Herman (1989) and Kurucz (1982) for predicting site index in the test data set was compared using a t-test for each continentality stratum.

According to the climate-specific height growth model (Eq. 4.5.1), different height growth patterns were found for the two continentality strata as well as for the different values of site index, which were most pronounced at breast height ages above 80 years (Figure 4.5.1). The climate-specific model was more precise, *i.e.*, had a lower error, (PMSE= 0.50) than the simple model (not shown, PMSE = 0.69). The climate-specific model was

generally not biased, while the simple model overpredicted height growth of trees at ages above 110 years, and Kurucz's model overpredicted height at ages 10-40 years and underpredicted height for trees over 55 years breast height age (Figure 4.5.2).

Equation 4.5.1

$$H = 1.3 + MLM\left\{(S-1.3)\frac{1+e^{[8.704-1.306\ln(50)-0.980\ln(S-1.3)]}}{1+e^{[8.704-1.306\ln A-0.980\ln(S-1.3)]}}\right\} + SS\left\{(S-1.3)\frac{1+e^{[9.761-1.549\ln(50)-1.109\ln(S-1.3)]}}{1+e^{[9.761-1.549\ln A-1.109\ln(S-1.3)]}}\right\}$$

where H = top height (m); S = site index (top height @ 50 yr bh); A = breast height age (yr); e = the base of ln; ln = natural logarithm; MLM and SS = 0 or 1, respectively, depending on the continentality stratum as defined above.

The climate-specific site index model (Eq. 4.5.2) was displayed as two separate tables for the continentality strata (Tables 4.5.2 and 4.5.3). When tested against the independent data, the climate-specific model again was more precise (PMSE = 0.59) than the simple model (not shown, PMSE = 0.73). The estimate of height from the climate-specific model was not biased for either the MLM or the SS strata, while the simple model and Kurucz's model were significantly biased for the MLM stratum, and Hoyer and Hermans' model was significantly biased for the SS stratum (Table 4.5.4).

Equation 4.5.2

$$S = 1.3 + MLM\left\{0.694(50-A)A^{-0.558} + 0.368(H-1.3) + 31.771(H-1.3)A^{-1}\right\} +$$
$$SS\left\{0.592(50-A)A^{-0.578} + 0.183(H-1.3) + 41.659(H-1.3)A^{-1}\right\}$$

where H = top height (m); S = site index (top height @ 50 yr bh); A = breast height age (yr); MLM and SS = 0 or 1, respectively, depending on the continentality stratum as defined above.

Due to their greater precision and lower bias, these new climate-specific height growth and site index models are recommended for application within the age range of 15 to 160 years in southern coastal British Columbia south of the transect between Lillooet and Port McNeill.

Table 4.5.1. General statistics for all study stands and the stands used for calibration and testing.

		Breast height age (years)	Top height (m)	Site index (m @ 50yr bh)
Calibration data	Minimum	37	7.7	4.8
N = 67	Mean	92	23.7	17.6
	Maximum	312	55.0	36.7
	Std. Dev.	51	8.6	7.9
Test data	Minimum	36	8.9	4.6
N = 31	Mean	82	22.0	18.2
	Maximum	173	32.3	36.4
	Std. Dev.	38	5.1	8.4
All data	Minimum	36	7.7	4.6
N = 98	Mean	89	23.1	17.8
	Maximum	312	55.0	36.7
	Std. Dev.	48	7.7	8.0
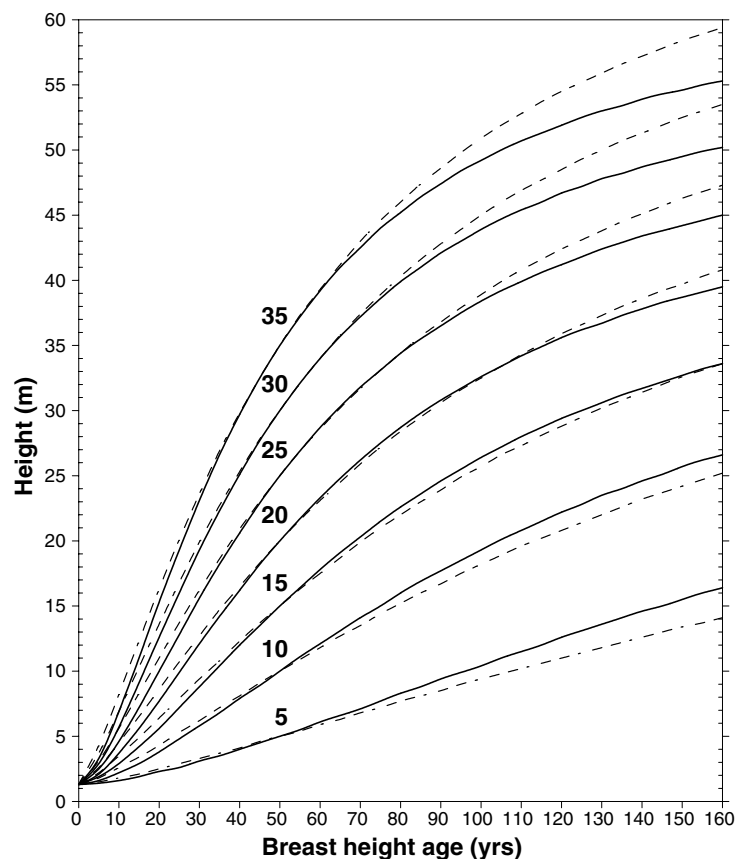
Figure 4.5.1. Climate-specific height growth curves for Pacific silver fir in southern coastal British Columbia for various site index values (Equation 4.5.1). Dashed lines represent the maritime and maritime-submaritime transition (MLM) continentality stratum, solid lines represent the submaritime and subcontinental (SS) continentality stratum.
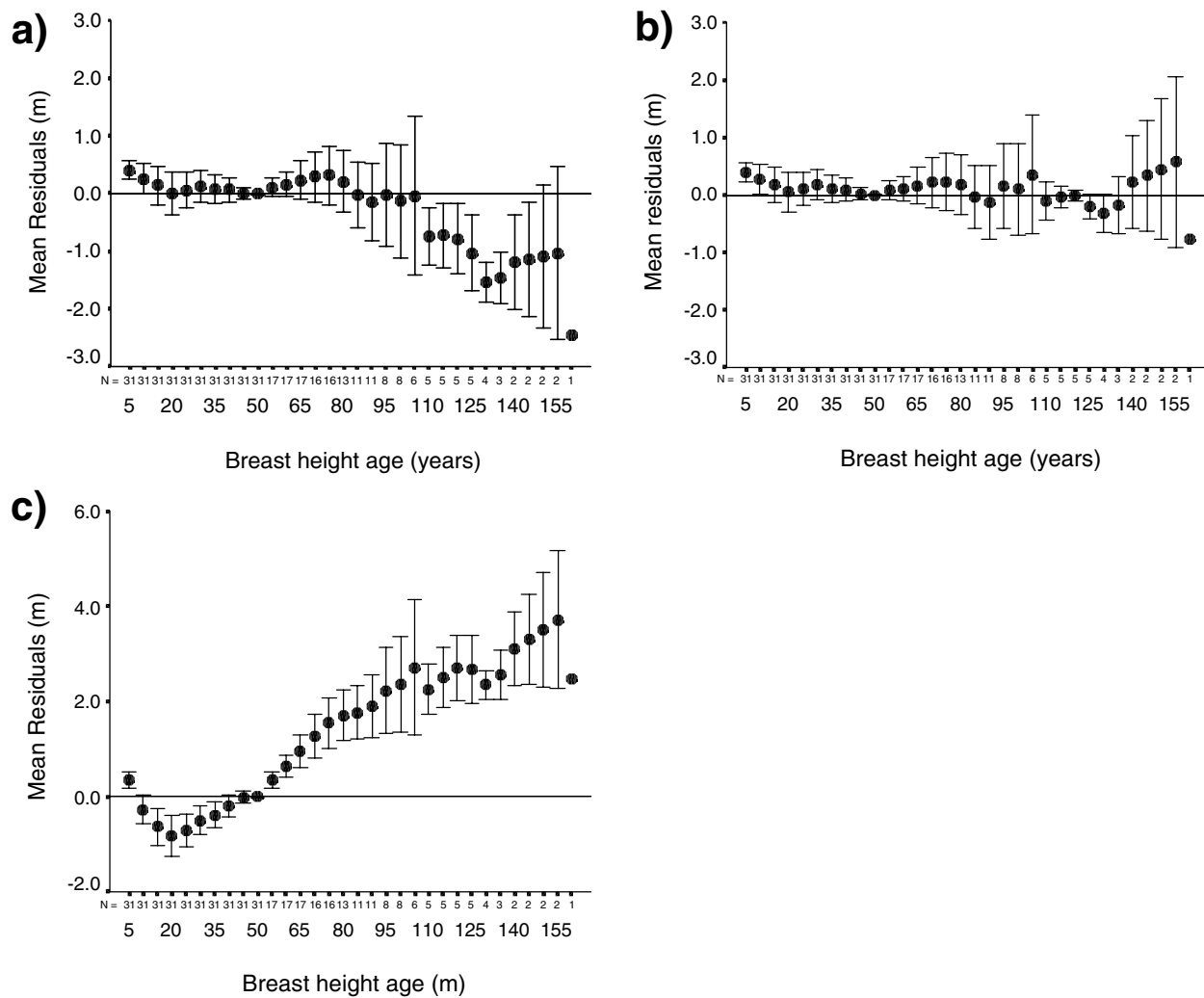
Figure 4.5.2. Validation of height/age models using the test data set. Mean and two standard errors of residuals as a function of breast height age of (a) the simple polymorphic model, (b) the climate-specific model (Eq. 4.5.1), and (c) Kuruzc's model. N is the number of observations used to calculate the error bars.

Table 4.5.2. Site index table for Pacific silver fir in the maritime and maritime-submaritime transition region of southern BC (MLM).

| Age @ bh	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	Age @ bh
12	16.5	23.8	31.1	38.4																											12
14	14.5	20.8	27.1	33.4	39.7																										14
16	12.9	18.5	24.0	29.6	35.2																										16
18	11.6	16.6	21.6	26.6	31.6	36.6																									18
20	10.6	15.1	19.6	24.2	28.7	33.2	37.8																								20
22	9.7	13.8	18.0	22.1	26.3	30.4	34.6	38.8																							22
24	8.9	12.8	16.6	20.4	24.3	28.1	32.0	35.8	39.6																						24
26	8.3	11.9	15.4	19.0	22.6	26.1	29.7	33.3	36.8																						26
28	7.7	11.1	14.4	17.7	21.1	24.4	27.8	31.1	34.4	37.8																					28
30	7.2	10.3	13.5	16.6	19.8	22.9	26.1	29.2	32.3	35.5	38.6																				30
32	6.7	9.7	12.7	15.7	18.6	21.6	24.6	27.5	30.5	33.5	36.4	39.4																			32
34	6.3	9.2	12.0	14.8	17.6	20.4	23.2	26.0	28.9	31.7	34.5	37.3																			34
36	6.0	8.6	11.3	14.0	16.7	19.4	22.0	24.7	27.4	30.1	32.8	35.4	38.1																		36
38	5.6	8.2	10.7	13.3	15.9	18.4	21.0	23.5	26.1	28.6	31.2	33.8	36.3	38.9																	38
40	5.3	7.8	10.2	12.7	15.1	17.6	20.0	22.4	24.9	27.3	29.8	32.2	34.7	37.1	39.6																40
42	5.0	7.4	9.7	12.1	14.4	16.8	19.1	21.5	23.8	26.2	28.5	30.9	33.2	35.6	37.9																42
44	4.7	7.0	9.3	11.5	13.8	16.0	18.3	20.6	22.8	25.1	27.3	29.6	31.9	34.1	36.4	38.6															44
46	4.5	6.7	8.9	11.0	13.2	15.4	17.6	19.7	21.9	24.1	26.3	28.4	30.6	32.8	35.0	37.2	39.3														46
48	4.3	6.4	8.5	10.6	12.7	14.8	16.9	19.0	21.1	23.2	25.3	27.4	29.5	31.6	33.7	35.8	37.9														48
50	4.0	6.1	8.1	10.1	12.2	14.2	16.2	18.3	20.3	22.3	24.4	26.4	28.4	30.5	32.5	34.5	36.6	38.6													50
52		5.8	7.8	9.7	11.7	13.7	15.6	17.6	19.6	21.5	23.5	25.5	27.5	29.4	31.4	33.4	35.3	37.3	39.3												52
54		5.5	7.5	9.4	11.3	13.2	15.1	17.0	18.9	20.8	22.7	24.6	26.5	28.5	30.4	32.3	34.2	36.1	38.0	39.9											54
56		5.3	7.2	9.0	10.9	12.7	14.6	16.4	18.3	20.1	22.0	23.8	25.7	27.6	29.4	31.3	33.1	35.0	36.8	38.7											56
58		5.1	6.9	8.7	10.5	12.3	14.1	15.9	17.7	19.5	21.3	23.1	24.9	26.7	28.5	30.3	32.1	33.9	35.7	37.5	39.3										58
60		4.9	6.6	8.4	10.1	11.9	13.6	15.4	17.1	18.9	20.7	22.4	24.2	25.9	27.7	29.4	31.2	32.9	34.7	36.4	38.2										60
62		4.7	6.4	8.1	9.8	11.5	13.2	14.9	16.6	18.3	20.0	21.8	23.5	25.2	26.9	28.6	30.3	32.0	33.7	35.4	37.1	38.9									62
64		4.5	6.1	7.8	9.5	11.1	12.8	14.5	16.1	17.8	19.5	21.1	22.8	24.5	26.1	27.8	29.5	31.2	32.8	34.5	36.2	37.8	39.5								64
66		4.3	5.9	7.5	9.2	10.8	12.4	14.1	15.7	17.3	18.9	20.6	22.2	23.8	25.5	27.1	28.7	30.3	32.0	33.6	35.2	36.8	38.5								66
68		4.1	5.7	7.3	8.9	10.5	12.1	13.7	15.2	16.8	18.4	20.0	21.6	23.2	24.8	26.4	28.0	29.6	31.2	32.7	34.3	35.9	37.5	39.1							68
70			5.5	7.1	8.6	10.2	11.7	13.3	14.8	16.4	17.9	19.5	21.1	22.6	24.2	25.7	27.3	28.8	30.4	31.9	33.5	35.1	36.6	38.2	39.7						70
72			5.3	6.8	8.3	9.9	11.4	12.9	14.4	16.0	17.5	19.0	20.5	22.1	23.6	25.1	26.6	28.1	29.7	31.2	32.7	34.2	35.8	37.3	38.8						72
74			5.1	6.6	8.1	9.6	11.1	12.6	14.1	15.6	17.0	18.5	20.0	21.5	23.0	24.5	26.0	27.5	29.0	30.5	32.0	33.5	34.9	36.4	37.9	39.4					74
76			4.9	6.4	7.9	9.3	10.8	12.2	13.7	15.1	16.6	18.1	19.6	21.0	22.5	23.9	25.4	26.9	28.3	29.8	31.3	32.7	34.2	35.6	37.1	38.6					76
78			4.8	6.2	7.6	9.1	10.5	11.9	13.4	14.8	16.2	17.7	19.1	20.5	22.0	23.4	24.8	26.3	27.7	29.1	30.6	32.0	33.4	34.9	36.3	37.7	39.2				78
80			4.6	6.0	7.4	8.8	10.2	11.6	13.0	14.5	15.9	17.3	18.7	20.1	21.5	22.9	24.3	25.7	27.1	28.5	29.9	31.3	32.7	34.2	35.6	37.0	38.4	39.8			80
82			4.4	5.8	7.2	8.6	10.0	11.4	12.7	14.1	15.5	16.9	18.3	19.6	21.0	22.4	23.8	25.2	26.6	27.9	29.3	30.7	32.1	33.5	34.8	36.2	37.6	39.0			82
84			4.3	5.7	7.0	8.4	9.7	11.1	12.4	13.8	15.2	16.5	17.9	19.2	20.6	21.9	23.3	24.7	26.0	27.4	28.7	30.1	31.4	32.7	34.2	35.5	36.9	38.2	39.6		84
86			4.1	5.5	6.8	8.2	9.5	10.8	12.2	13.5	14.8	16.2	17.5	18.8	20.2	21.5	22.8	24.2	25.5	26.8	28.2	29.5	30.8	32.2	33.5	34.8	36.2	37.5	38.8		86
88			4.0	5.3	6.6	7.9	9.3	10.6	11.9	13.2	14.5	15.8	17.1	18.4	19.8	21.1	22.4	23.7	25.0	26.3	27.6	28.9	30.3	31.6	32.9	34.2	35.5	36.8	38.1	39.4	88
90				5.2	6.5	7.7	9.0	10.3	11.6	12.9	14.2	15.5	16.8	18.1	19.4	20.7	21.9	23.2	24.5	25.8	27.1	28.4	29.7	31.0	32.3	33.6	34.9	36.2	37.4	38.7	90
92				5.0	6.3	7.6	8.8	10.1	11.4	12.6	13.9	15.2	16.5	17.7	19.0	20.3	21.5	22.8	24.1	25.3	26.6	27.9	29.2	30.4	31.7	33.0	34.2	35.5	36.8	38.1	92
94				4.9	6.1	7.4	8.6	9.9	11.1	12.4	13.6	14.9	16.1	17.4	18.6	19.9	21.1	22.4	23.6	24.9	26.1	27.4	28.7	29.9	31.2	32.4	33.7	34.9	36.2	37.4	94
96				4.7	6.0	7.2	8.4	9.7	10.9	12.1	13.4	14.6	15.8	17.1	18.3	19.5	20.8	22.0	23.2	24.5	25.7	26.9	28.2	29.4	30.6	31.9	33.1	34.3	35.6	36.8	96
98				4.6	5.8	7.0	8.2	9.4	10.7	11.9	13.1	14.3	15.5	16.7	18.0	19.2	20.4	21.6	22.8	24.0	25.3	26.5	27.7	28.9	30.1	31.3	32.5	33.8	35.0	36.2	98
100				4.4	5.6	6.8	8.0	9.2	10.4	11.6	12.8	14.0	15.2	16.4	17.6	18.8	20.0	21.2	22.4	23.6	24.8	26.0	27.2	28.4	29.6	30.8	32.0	33.2	34.4	35.6	100
102				4.3	5.5	6.7	7.9	9.0	10.2	11.4	12.6	13.8	15.0	16.1	17.3	18.5	19.7	20.9	22.1	23.2	24.4	25.6	26.8	28.0	29.2	30.3	31.5	32.7	33.9	35.1	102
104				4.2	5.4	6.5	7.7	8.9	10.0	11.2	12.4	13.5	14.7	15.9	17.0	18.2	19.4	20.5	21.7	22.9	24.0	25.2	26.4	27.5	28.7	29.9	31.0	32.2	33.4	34.5	104
106				4.1	5.2	6.4	7.5	8.7	9.8	11.0	12.1	13.3	14.4	15.6	16.7	17.9	19.0	20.2	21.3	22.5	23.7	24.8	26.0	27.1	28.3	29.4	30.6	31.7	32.9	34.0	106
108				4.0	5.1	6.2	7.4	8.5	9.6	10.8	11.9	13.1	14.2	15.3	16.5	17.6	18.7	19.9	21.0	22.1	23.3	24.4	25.6	26.7	27.8	29.0	30.1	31.2	32.4	33.5	108
110					5.0	6.1	7.2	8.3	9.5	10.6	11.7	12.8	13.9	15.1	16.2	17.3	18.4	19.6	20.7	21.8	22.9	24.1	25.2	26.3	27.4	28.5	29.7	30.8	31.9	33.0	110
112					4.8	5.9	7.1	8.2	9.3	10.4	11.5	12.6	13.7	14.8	15.9	17.0	18.2	19.3	20.4	21.5	22.6	23.7	24.8	25.9	27.0	28.1	29.2	30.4	31.5	32.6	112
114					4.7	5.8	6.9	8.0	9.1	10.2	11.3	12.4	13.5	14.6	15.7	16.8	17.9	19.0	20.1	21.2	22.3	23.4	24.5	25.6	26.7	27.7	28.8	29.9	31.0	32.1	114
116					4.6	5.7	6.8	7.8	8.9	10.0	11.1	12.2	13.3	14.4	15.4	16.5	17.6	18.7	19.8	20.9	21.9	23.0	24.1	25.2	26.3	27.4	28.4	29.5	30.6	31.7	116
118					4.5	5.6	6.6	7.7	8.8	9.8	10.9	12.0	13.1	14.1	15.2	16.3	17.3	18.4	19.5	20.6	21.6	22.7	23.8	24.8	25.9	27.0	28.1	29.1	30.2	31.3	118
120					4.4	5.4	6.5	7.5	8.6	9.7	10.7	11.8	12.8	13.9	15.0	16.0	17.1	18.1	19.2	20.3	21.3	22.4	23.4	24.5	25.6	26.6	27.7	28.7	29.8	30.9	120
122					4.3	5.3	6.4	7.4	8.5	9.5	10.5	11.6	12.6	13.7	14.7	15.8	16.8	17.9	18.9	20.0	21.0	22.1	23.1	24.2	25.2	26.3	27.3	28.4	29.4	30.5	122
124					4.2	5.2	6.2	7.3	8.3	9.3	10.4	11.4	12.5	13.5	14.5	15.6	16.6	17.6	18.7	19.7	20.8	21.8	22.8	23.9	24.9	25.9	27.0	28.0	29.1	30.1	124
126					4.0	5.1	6.1	7.1	8.2	9.2	10.2	11.2	12.3	13.3	14.3	15.3	16.4	17.4	18.4	19.4	20.5	21.5	22.5	23.6	24.6	25.6	26.6	27.7	28.7	29.7	126
128						5.0	6.0	7.0	8.0	9.0	10.0	11.1	12.1	13.1	14.1	15.1	16.1	17.2	18.2	19.2	20.2	21.2	22.2	23.3	24.3	25.3	26.3	27.3	28.3	29.4	128
130						4.9	5.9	6.9	7.9	8.9	9.9	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9	19.9	21.0	22.0	23.0	24.0	25.0	26.0	27.0	28.0	29.0	130
132						4.7	5.7	6.7	7.7	8.7	9.7	10.7	11.7	12.7	13.7	14.7	15.7	16.7	17.7	18.7	19.7	20.7	21.7	22.7	23.7	24.7	25.7	26.7	27.7	28.7	132
134						4.6	5.6	6.6	7.6	8.6	9.6	10.6	11.6	12.5	13.5	14.5	15.5	16.5	17.5	18.5	19.5	20.4	21.4	22.4	23.4	24.4	25.4	26.4	27.4	28.3	134
136						4.5	5.5	6.5	7.5	8.4	9.4	10.4	11.4	12.4	13.3	14.3	15.3	16.3	17.3	18.2	19.2	20.2	21.2	22.1	23.1	24.1	25.1	26.1	27.0	28.0	136
138						4.4	5.4	6.4	7.3	8.3	9.3	10.3	11.2	12.2	13.2	14.1	15.1	16.1	17.0	18.0	19.0	19.9	20.9	21.9	22.9	23.8	24.8	25.8	26.7	27.7	138
140						4.3	5.3	6.3	7.2	8.2	9.1	10.1	11.1	12.0	13.0	13.9	14.9	15.9	16.8	17.8	18.8	19.7	20.7	21.6	22.6	23.6	24.5	25.5	26.4	27.4	140
142						4.2	5.2	6.1	7.1	8.1	9.0	10.0	10.9	11.9	12.8	13.8	14.7	15.7	16.6	17.6	18.5	19.5	20.4	21.4	22.3	23.3	24.2	25.2	26.1	27.1	142
144						4.1	5.1	6.0	7.0	7.9	8.9	9.8	10.8	11.7	12.6	13.6	14.5	15.5	16.4	17.4	18.3	19.3	20.2	21.1	22.1	23.0	24.0	24.9	25.9	26.8	144
146						4.1	5.0	5.9	6.9	7.8	8.7	9.7	10.6	11.5	12.5	13.4	14.4	15.3	16.2	17.2	18.1	19.0	20.0	20.9	21.8	22.8	23.7	24.7	25.6	26.5	146
148						4.0	4.9	5.8	6.8	7.7	8.6	9.5	10.5	11.4	12.3	13.3	14.2	15.1	16.0	17.0	17.9	18.8	19.8	20.7	21.6	22.5	23.5	24.4	25.3	26.3	148
150							4.8	5.7	6.6	7.6	8.5	9.4	10.3	11.2	12.2	13.1	14.0	14.9	15.9	16.8	17.7	18.6	19.5	20.5	21.4	22.3	23.2	24.1	25.1	26.0	150
152							4.7	5.6	6.5	7.4	8.4	9.3	10.2	11.1	12.0	12.9	13.8	14.8	15.7	16.6	17.5	18.4	19.3	20.2	21.2	22.1	23.0	23.9	24.8	25.7	152
154							4.6	5.5	6.4	7.3	8.2	9.1	10.1	11.0	11.9	12.8	13.7	14.6	15.5	16.4	17.3	18.2	19.1	20.0	20.9	21.8	22.7	23.6	24.6	25.5	154
156							4.5	5.4	6.3	7.2	8.1	9.0	9.9	10.8	11.7	12.6	13.5	14.4	15.3	16.2	17.1	18.0	18.9	19.8	20.7	21.6	22.5	23.4	24.3	25.2	156
158							4.4	5.3	6.2	7.1	8.0	8.9	9.8	10.7	11.6	12.5	13.4	14.3	15.2	16.0	16.9	17.8	18.7	19.6	20.5	21.4	22.3	23.2	24.1	25.0	158
160							4.4	5.2	6.1	7.0	7.9	8.8	9.7	10.6	11.4	12.3	13.2	14.1	15.0	15.9	16.8	17.6	18.5	19.4	20.3	21.2	22.1	23.0	23.9	24.7	160

Mountain Hemlock Zone

Table 4.5.3. Site index table for Pacific silver fir in the submaritime and subcontinental regions of southern BC (SS).

Age @ bh	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0	26.0	28.0	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0	50.0	52.0	54.0	56.0	58.0	60.0	62.0	Age @ bh
12	16.0	22.1	28.1	34.1	40.2																										12
14	14.1	19.4	24.7	30.0	35.2	40.5																									14
16	12.7	17.4	22.1	26.8	31.5	36.2	40.9																								16
18	11.5	15.7	20.0	24.3	28.5	32.8	37.1	41.4																							18
20	10.5	14.4	18.3	22.2	26.1	30.1	34.0	37.9	41.8																						20
22	9.7	13.3	16.9	20.5	24.2	27.8	31.4	35.0	38.7																						22
24	8.9	12.3	15.7	19.1	22.5	25.9	29.2	32.6	36.0	39.4																					24
26	8.3	11.5	14.7	17.8	21.0	24.2	27.4	30.6	33.7	36.9	40.1																				26
28	7.7	10.7	13.7	16.8	19.8	22.8	25.8	28.8	31.8	34.8	37.8	40.8																			28
30	7.2	10.1	12.9	15.8	18.7	21.5	24.4	27.2	30.1	32.9	35.8	38.6	41.5																		30
32	6.8	9.5	12.2	14.9	17.7	20.4	23.1	25.8	28.6	31.3	34.0	36.7	39.4																		32
34	6.4	9.0	11.6	14.2	16.8	19.4	22.0	24.6	27.2	29.8	32.4	35.0	37.6	40.2																	34
36	6.0	8.5	11.0	13.5	16.0	18.5	21.0	23.5	26.0	28.5	31.0	33.5	36.0	38.5	41.0																36
38	5.6	8.1	10.5	12.9	15.3	17.7	20.1	22.5	24.9	27.3	29.7	32.1	34.6	37.0	39.4																38
40	5.3	7.6	10.0	12.3	14.6	17.0	19.3	21.6	23.9	26.3	28.6	30.9	33.2	35.6	37.9	40.2															40
42	5.0	7.3	9.5	11.8	14.0	16.3	18.5	20.8	23.0	25.3	27.5	29.8	32.0	34.3	36.5	38.8	41.0														42
44	4.7	6.9	9.1	11.3	13.5	15.7	17.8	20.0	22.2	24.4	26.6	28.7	30.9	33.1	35.3	37.5	39.6														44
46	4.5	6.6	8.7	10.8	13.0	15.1	17.2	19.3	21.4	23.6	25.7	27.8	29.9	32.0	34.1	36.3	38.4	40.5													46
48	4.2	6.3	8.4	10.4	12.5	14.5	16.6	18.7	20.7	22.8	24.8	26.9	29.0	31.0	33.1	35.2	37.2	39.3													48
50	4.0	6.0	8.0	10.0	12.0	14.0	16.1	18.1	20.1	22.1	24.1	26.1	28.1	30.1	32.1	34.1	36.1	38.1	40.1												50
52		5.8	7.7	9.7	11.6	13.6	15.5	17.5	19.5	21.4	23.4	25.3	27.3	29.3	31.2	33.2	35.1	37.1	39.0	41.0											52
54		5.5	7.4	9.3	11.2	13.2	15.1	17.0	18.9	20.8	22.7	24.6	26.5	28.5	30.4	32.3	34.2	36.1	38.0	39.9											54
56		5.3	7.1	9.0	10.9	12.7	14.6	16.5	18.4	20.2	22.1	24.0	25.8	27.7	29.6	31.5	33.3	35.2	37.1	38.9	40.8										56
58		5.0	6.9	8.7	10.5	12.4	14.2	16.0	17.9	19.7	21.5	23.4	25.2	27.0	28.9	30.7	32.5	34.3	36.2	38.0	39.8										58
60		4.8	6.6	8.4	10.2	12.0	13.8	15.6	17.4	19.2	21.0	22.8	24.6	26.4	28.2	30.0	31.8	33.5	35.3	37.1	38.9	40.7									60
62		4.6	6.4	8.1	9.9	11.7	13.4	15.2	16.9	18.7	20.5	22.2	24.0	25.7	27.5	29.3	31.0	32.8	34.6	36.3	38.1	39.8									62
64		4.4	6.1	7.9	9.6	11.3	13.1	14.8	16.5	18.2	20.0	21.7	23.4	25.2	26.9	28.6	30.4	32.1	33.8	35.5	37.3	39.0	40.7								64
66		4.2	5.9	7.6	9.3	11.0	12.7	14.4	16.1	17.8	19.5	21.2	22.9	24.6	26.3	28.0	29.7	31.4	33.1	34.8	36.5	38.2	39.9								66
68		4.0	5.7	7.4	9.1	10.7	12.4	14.1	15.7	17.4	19.1	20.8	22.4	24.1	25.8	27.4	29.1	30.8	32.5	34.1	35.8	37.5	39.1								68
70			5.5	7.2	8.8	10.4	12.1	13.7	15.4	17.0	18.7	20.3	22.0	23.6	25.2	26.9	28.5	30.2	31.8	33.5	35.1	36.8	38.4	40.1							70
72			5.3	6.9	8.6	10.2	11.8	13.4	15.0	16.7	18.3	19.9	21.5	23.1	24.8	26.4	28.0	29.6	31.2	32.9	34.5	36.1	37.7	39.3							72
74			5.1	6.7	8.3	9.9	11.5	13.1	14.7	16.3	17.9	19.5	21.1	22.7	24.3	25.9	27.5	29.1	30.7	32.3	33.9	35.5	37.0	38.6	40.2						74
76			5.0	6.5	8.1	9.7	11.3	12.8	14.4	16.0	17.5	19.1	20.7	22.3	23.8	25.4	27.0	28.6	30.1	31.7	33.3	34.8	36.4	38.0	39.6						76
78			4.8	6.3	7.9	9.4	11.0	12.5	14.1	15.7	17.2	18.8	20.3	21.9	23.4	25.0	26.5	28.1	29.6	31.2	32.7	34.3	35.8	37.4	38.9	40.5					78
80			4.6	6.2	7.7	9.2	10.8	12.3	13.8	15.3	16.9	18.4	19.9	21.5	23.0	24.5	26.1	27.6	29.1	30.7	32.2	33.7	35.2	36.8	38.3	39.8					80
82			4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.6	18.1	19.6	21.1	22.6	24.1	25.6	27.1	28.7	30.2	31.7	33.2	34.7	36.2	37.7	39.2					82
84			4.3	5.8	7.3	8.8	10.3	11.8	13.3	14.8	16.3	17.8	19.2	20.7	22.2	23.7	25.2	26.7	28.2	29.7	31.2	32.7	34.2	35.7	37.2	38.7	40.2				84
86			4.2	5.6	7.1	8.6	10.1	11.5	13.0	14.5	16.0	17.4	18.9	20.4	21.9	23.3	24.8	26.3	27.8	29.3	30.7	32.2	33.7	35.2	36.6	38.1	39.6				86
88			4.0	5.5	6.9	8.4	9.9	11.3	12.8	14.2	15.7	17.2	18.6	20.1	21.5	23.0	24.4	25.9	27.4	28.8	30.3	31.7	33.2	34.7	36.1	37.6	39.0				88
90				5.3	6.8	8.2	9.7	11.1	12.5	14.0	15.4	16.9	18.3	19.8	21.2	22.6	24.1	25.5	27.0	28.4	29.9	31.3	32.7	34.2	35.6	37.1	38.5	40.0			90
92				5.2	6.6	8.0	9.5	10.9	12.3	13.7	15.2	16.6	18.0	19.5	20.9	22.3	23.7	25.2	26.6	28.0	29.4	30.9	32.3	33.7	35.2	36.6	38.0	39.4			92
94				5.0	6.4	7.9	9.3	10.7	12.1	13.5	14.9	16.3	17.7	19.2	20.6	22.0	23.4	24.8	26.2	27.6	29.0	30.5	31.9	33.3	34.7	36.1	37.5	38.9	40.3		94
96				4.9	6.3	7.7	9.1	10.5	11.9	13.3	14.7	16.1	17.5	18.9	20.3	21.7	23.1	24.5	25.9	27.3	28.7	30.1	31.5	32.9	34.3	35.7	37.1	38.5	39.9		96
98				4.7	6.1	7.5	8.9	10.3	11.7	13.1	14.4	15.8	17.2	18.6	20.0	21.4	22.8	24.1	25.5	26.9	28.3	29.7	31.1	32.5	33.8	35.2	36.6	38.0	39.4		98
100				4.6	6.0	7.4	8.7	10.1	11.5	12.8	14.2	15.6	17.0	18.3	19.7	21.1	22.5	23.8	25.2	26.6	27.9	29.3	30.7	32.1	33.4	34.8	36.2	37.6	38.9	40.3	100
102				4.5	5.8	7.2	8.6	9.9	11.3	12.6	14.0	15.4	16.7	18.1	19.4	20.8	22.2	23.5	24.9	26.2	27.6	29.0	30.3	31.7	33.0	34.4	35.8	37.1	38.5	39.8	102
104				4.4	5.7	7.1	8.4	9.8	11.1	12.4	13.8	15.1	16.5	17.8	19.2	20.5	21.9	23.2	24.6	25.9	27.3	28.6	30.0	31.3	32.7	34.0	35.4	36.7	38.1	39.4	104
106				4.2	5.6	6.9	8.2	9.6	10.9	12.3	13.6	14.9	16.3	17.6	18.9	20.3	21.6	22.9	24.3	25.6	27.0	28.3	29.6	31.0	32.3	33.6	35.0	36.3	37.6	39.0	106
108				4.1	5.4	6.8	8.1	9.4	10.7	12.1	13.4	14.7	16.0	17.4	18.7	20.0	21.3	22.7	24.0	25.3	26.6	28.0	29.3	30.6	31.9	33.3	34.6	35.9	37.2	38.6	108
110				4.0	5.3	6.6	7.9	9.3	10.6	11.9	13.2	14.5	15.8	17.1	18.5	19.8	21.1	22.4	23.7	25.0	26.3	27.7	29.0	30.3	31.6	32.9	34.2	35.5	36.9	38.2	110
112					5.2	6.5	7.8	9.1	10.4	11.7	13.0	14.3	15.6	16.9	18.2	19.5	20.8	22.1	23.4	24.8	26.1	27.4	28.7	30.0	31.3	32.6	33.9	35.2	36.5	37.8	112
114					5.1	6.4	7.7	9.0	10.2	11.5	12.8	14.1	15.4	16.7	18.0	19.3	20.6	21.9	23.2	24.5	25.8	27.1	28.4	29.7	31.0	32.2	33.5	34.8	36.1	37.4	114
116					4.9	6.2	7.5	8.8	10.1	11.4	12.7	13.9	15.2	16.5	17.8	19.1	20.4	21.6	22.9	24.2	25.5	26.8	28.1	29.4	30.6	31.9	33.2	34.5	35.8	37.1	116
118					4.8	6.1	7.4	8.7	9.9	11.2	12.5	13.8	15.0	16.3	17.6	18.9	20.1	21.4	22.7	24.0	25.2	26.5	27.8	29.1	30.3	31.6	32.9	34.2	35.4	36.7	118
120					4.7	6.0	7.3	8.5	9.8	11.1	12.3	13.6	14.9	16.1	17.4	18.6	19.9	21.2	22.4	23.7	25.0	26.2	27.5	28.8	30.0	31.3	32.6	33.8	35.1	36.4	120
122					4.6	5.9	7.1	8.4	9.6	10.9	12.2	13.4	14.7	15.9	17.2	18.4	19.7	21.0	22.2	23.5	24.7	26.0	27.2	28.5	29.8	31.0	32.3	33.5	34.8	36.1	122
124					4.5	5.8	7.0	8.2	9.5	10.7	12.0	13.2	14.5	15.7	17.0	18.2	19.5	20.7	22.0	23.2	24.5	25.7	27.0	28.2	29.5	30.7	32.0	33.2	34.5	35.7	124
126					4.4	5.6	6.9	8.1	9.4	10.6	11.8	13.1	14.3	15.6	16.8	18.0	19.3	20.5	21.8	23.0	24.3	25.5	26.7	28.0	29.2	30.5	31.7	32.9	34.2	35.4	126
128					4.3	5.5	6.8	8.0	9.2	10.5	11.7	12.9	14.2	15.4	16.6	17.9	19.1	20.3	21.6	22.8	24.0	25.3	26.5	27.7	29.0	30.2	31.4	32.7	33.9	35.1	128
130					4.2	5.4	6.6	7.9	9.1	10.3	11.5	12.8	14.0	15.2	16.4	17.7	18.9	20.1	21.3	22.6	23.8	25.0	26.3	27.5	28.7	29.9	31.2	32.4	33.6	34.8	130
132					4.1	5.3	6.5	7.7	9.0	10.2	11.4	12.6	13.8	15.1	16.3	17.5	18.7	19.9	21.1	22.4	23.6	24.8	26.0	27.2	28.5	29.7	30.9	32.1	33.3	34.5	132
134					4.0	5.2	6.4	7.6	8.8	10.0	11.3	12.5	13.7	14.9	16.1	17.3	18.5	19.7	20.9	22.2	23.4	24.6	25.8	27.0	28.2	29.4	30.6	31.8	33.1	34.3	134
136						5.1	6.3	7.5	8.7	9.9	11.1	12.3	13.5	14.7	15.9	17.1	18.3	19.6	20.8	22.0	23.2	24.4	25.6	26.8	28.0	29.2	30.4	31.6	32.8	34.0	136
138						5.0	6.2	7.4	8.6	9.8	11.0	12.2	13.4	14.6	15.8	17.0	18.2	19.4	20.6	21.8	23.0	24.2	25.4	26.6	27.8	28.9	30.1	31.3	32.5	33.7	138
140						4.9	6.1	7.3	8.5	9.7	10.9	12.0	13.2	14.4	15.6	16.8	18.0	19.2	20.4	21.6	22.8	24.0	25.1	26.3	27.5	28.7	29.9	31.1	32.3	33.5	140
142						4.8	6.0	7.2	8.4	9.5	10.7	11.9	13.1	14.3	15.5	16.6	17.8	19.0	20.2	21.4	22.6	23.8	24.9	26.1	27.3	28.5	29.7	30.9	32.0	33.2	142
144						4.7	5.9	7.1	8.2	9.4	10.6	11.8	13.0	14.1	15.3	16.5	17.7	18.8	20.0	21.2	22.4	23.6	24.7	25.9	27.1	28.3	29.5	30.6	31.8	33.0	144
146						4.6	5.8	7.0	8.1	9.3	10.5	11.7	12.8	14.0	15.2	16.3	17.5	18.7	19.9	21.0	22.2	23.4	24.5	25.7	26.9	28.1	29.2	30.4	31.6	32.7	146
148						4.5	5.7	6.9	8.0	9.2	10.4	11.5	12.7	13.9	15.0	16.2	17.4	18.5	19.7	20.9	22.0	23.2	24.4	25.5	26.7	27.9	29.0	30.2	31.3	32.5	148
150						4.4	5.6	6.8	7.9	9.1	10.2	11.4	12.6	13.7	14.9	16.0	17.2	18.4	19.5	20.7	21.8	23.0	24.2	25.3	26.5	27.6	28.8	30.0	31.1	32.3	150
152						4.3	5.5	6.7	7.8	9.0	10.1	11.3	12.4	13.6	14.7	15.9	17.1	18.2	19.4	20.5	21.7	22.8	24.0	25.1	26.3	27.4	28.6	29.8	30.9	32.1	152
154						4.3	5.4	6.6	7.7	8.9	10.0	11.2	12.3	13.5	14.6	15.8	16.9	18.1	19.2	20.4	21.5	22.7	23.8	25.0	26.1	27.3	28.4	29.6	30.7	31.8	154
156						4.2	5.3	6.5	7.6	8.8	9.9	11.0	12.2	13.3	14.5	15.6	16.8	17.9	19.1	20.2	21.3	22.5	23.6	24.8	25.9	27.1	28.2	29.3	30.5	31.6	156
158						4.1	5.2	6.4	7.5	8.6	9.8	10.9	12.1	13.2	14.3	15.5	16.6	17.8	18.9	20.0	21.2	22.3	23.5	24.6	25.7	26.9	28.0	29.2	30.3	31.4	158
160						4.0	5.1	6.3	7.4	8.5	9.7	10.8	11.9	13.1	14.2	15.4	16.5	17.6	18.8	19.9	21.0	22.2	23.3	24.4	25.6	26.7	27.8	29.0	30.1	31.2	160

Table 4.5.4. Results of the paired t-tests ($\alpha = 0.05$) assessing bias using the measured site index (mSI) and the predicted site index from the simple polymorphic and climate-specific models of this study and from Kurucz's (1982) and Hoyer and Hermans' (1989) models. MLM and SS refer to the maritime/less maritime and submaritime/subcontinental continentality strata, respectively. Bold values are statistically significant.

	Continentality Stratum	mean	Std. Error of the mean	t	df	*p*-value
mSI - SI(simple)	MLM	0.34	0.148	**2.277**	17	**0.036**
	SS	-0.33	0.280	-1.175	12	0.263
mSI - SI(climate-specific)	MLM	0.05	0.134	0.355	17	0.727
	SS	0.19	0.278	-0.694	12	0.501
mSI - SI(Hoyer and Herman)	MLM	0.45	0.130	**3.473**	17	**0.003**
	SS	-0.62	0.293	-2.100	12	0.057
mSI - SI(Kuruzc)	MLM	-0.17	-0.231	-0.723	17	0.480
	SS	-1.47	0.336	**-4.368**	12	**0.001**

Summary

To improve estimates of site index for second-growth stands of Pacific silver fir across its native range in southern British Columbia, new climate-specific, polymorphic height growth and site index models were developed. Compared to conventional polymorphic models, these models provide more accurate estimates of height and site index as they account for the influence continentality on the growth of Pacific silver fir.

4.6 SOIL NUTRIENT REGIME

This section is based on Splechtna (1999b).

The site classification component of the biogeoclimatic ecosystem classification system is essentially based on three differentiating properties: climate (biogeoclimatic subzones or variants), soil moisture regimes (SMRs), and soil nutrient regimes (SNRs). SNRs are identified in the field using a number of easily observable soil morphological properties. However, it is assumed that each of the five SNRs represents a certain range of plant-available soil nutrients averaged over a period of several years (Pojar *et al.* 1987; Klinka *et al.* 1989). Although this assumption has been corroborated by several studies (*e.g.*, Klinka *et al.* 1994; Chen *et al.* 1998)), we do not know whether it holds for the coastal subalpine soils. Affected by cool climate and a short growing season, these soils differ significantly from low-elevation soils, generally by having a thick forest floor and a high organic matter content. Even if SNRs represent segments of a regional soil nutrient gradient, their significance in relation to forest growth is uncertain. Therefore, a study was carried out to quantitatively characterize field-identified SNRs in the coastal subalpine forest. Relationships between soil chemical properties and field-identified SNRs were examined and then soil chemistry and field-identified SNRs were related to site index of Pacific silver fir, which is a major timber crop species in this forest.

The study sites were selected across the entire native range of Pacific silver fir in southern BC as part of a high-elevation productivity study. The SMR and SNR of each site were identified using easily observable soil morphological properties and indicator plants (Green and Klinka 1994). Elevation was measured using an altimeter. The site index of Pacific silver fir was determined from stem analysis. The sites were stratified into four continentality strata (maritime, maritime-submaritime transition, submaritime, and subcontinental) using biogeoclimatic subzones or variants and the position of the site in relation to the Insular or Coast Mountains.

Seventy-nine study plots, each 20 x 20 m (0.04 ha) were located in the montane and subalpine forest. In each plot, samples of the entire forest floor and of the 0 to 30 cm depth of the mineral soil were collected from 12 sampling points. These 12 samples from each plot were combined into two samples (forest floor and mineral soil) for chemical analysis. The composite samples were analyzed for the following chemical properties: pH, total carbon (tC), total nitrogen (tN), mineralizable nitrogen (min-N), extractable phosphorus (P), sulphur (S), calcium (Ca), magnesium (Mg), and potassium (K). All nutrients were expressed as concentrations on a dry mass basis. To describe the quality of organic matter and nitrogen, two additional properties were calculated: C:N and min-N:tN ratios. The sum of extractable Ca, Mg, and K (sum of extractable bases, SEB) was used in the analyses.

To evaluate the potential of each soil chemical variable in order to discriminate between field-estimated SNRs, the plots were stratified according to three SNR classes: poor, medium, and rich (Table 4.6.1). Analysis of variance (ANOVA) and multiple comparison of means (using Bonferroni's adjustment) were carried out for each chemical variable to detect differences between the SNRs. Prior to analysis, a number of variables had to be transformed to meet the ANOVA prerequisite assumptions of homogeneity of variance and normality (Table 4.6.1).

To identify the combinations of variables that explain a considerable amount of variation between the plots without *a priori* classification, factor analysis based on a principal component analysis (PCA) was executed. The PCA was followed by a Varimax rotation procedure. To weigh all variables equally, they were standardized by transformation into z-scores (mean 0, standard deviation 1) prior to the analysis. The locations of the plots on the axes (factor scores) were used in subsequent analyses.

To create new, *a posteriori* soil nutrient classes that were separated based on both forest floor and mineral soil chemical properties, a discriminant analysis (DA) was employed. This analysis produced discriminant functions based on the soil properties that best separated the plots, and these functions were then used to classify the plots into new nutrient classes (A-C). The number of plots classified correctly by the discriminant functions according to the original field identification was assessed.

Table 4.6.1. Means and standard errors of the mean for the measured forest floor and mineral soil nutrient properties according to field-identified soil nutrient regimes. Values in the same row with the same letters were not significantly different (t-test; $\alpha = 0.05$); properties without letters did not show any significant differences between soil nutrient regimes.

Field-identified soil nutrient regime	Poor	Medium	Rich
Number of plots	23	35	21
Forest floor			
pH	3.9±0.1[a]	4.0±0.1[a]	4.3±0.1[b]
Total C (g kg^{-1})	446.9±4.3[b]	439.3±5.1[b]	412.7±9.5[a]
Total N (g kg^{-1})	7.7±0.4[a]	9.3±0.4[ab]	10.1±0.6[b]
C:N ratio*	64.7±5.8[b]	51.6±3.2[ba]	44.7±3.5[a]
Mineralizable-N (mg kg^{-1})*	124±6[a]	158±13[ab]	172±17[b]
Min-N:total N ratio *	0.02±0.002	0.02±0.002	0.02±0.002
Extractable S (mg kg^{-1})	59±17	57±17	55±18
Extractable P (mg kg^{-1})	90±8	84±7	87±10
SEB (g kg^{-1})*	3.6±0.3[a]	3.9±0.3[a]	5.4±0.6[b]
Mineral soil			
pH	4.6±0.1[ba]	4.5±0.1[a]	4.8±0.1[b]
Total C (g kg^{-1})	45.7±5.6	55.3±5.2	63.9±7.4
Total N (g kg^{-1})*	1.7±0.3[a]	2.8±0.5[ab]	4.5±1.1[b]
C:N ratio	34.2±3.5[b]	28.4±1.9[ba]	22.4±2.3[a]
Mineralizable-N (mg kg^{-1})*	9.1±1.8[a]	15.3±2.2[a]	33.3±4.9[b]
Min-N:total N ratio[1]	0.006±0.001[a]	0.008±0.001[ab]	0.012±0.002[b]
Extractable S (mg kg^{-1})	8.0±3.2[a]	10.3±3.7[b]	8.8±2.5[ab]
Extractable P (mg kg^{-1})[1]	17±4	10±2	15±4
SEB (g kg^{-1})*	0.14±0.04[a]	0.16±0.03[a]	0.59±0.15[b]

* Variables have been transformed using the natural logarithm or the square root

The relationships between the site index of Pacific silver fir and soil nutrient properties, factor scores or SNRs were examined by regression analysis: considering the strong influence of climate on fir productivity, elevation was always used as a covariate. To minimize the influence of SMR, we used only fresh and moist plots in this analysis (n = 42).

In general overall and plant-available nitrogen, as well as SEB increased from poor to medium to rich SNR, while S and P showed no obvious trends (Table 4.6.1). Of the properties with consistent trends, three forest floor properties (pH, organic matter content (tC), and SEB) and two mineral soil properties (min-N and SEB) showed a significant difference between poor to medium and richer sites. None of these properties showed a significant difference between poor and medium sites. This agrees with several studies in the area, which found that SNRs may be viewed as nitrogen-driven indices of plant-available nutrients (Klinka and Carter 1990; Klinka *et al.* 1994; Chen *et al.* 1998).

The first three axes of the factor analysis on forest floor properties explained 34%, 19%, and 15%, respectively, of the total variability in chemical properties among the plots. The first axis showed a highly positive association with pH, SEB (primarily extractable Ca and Mg), and a negative association with tC, while the second axis was positively associated with tN and negatively with the C:N-ratio. The third axis was positively associated with P, S and K. Even more of the variance in chemical properties of the mineral soil was explained by the first three factors (32%, 26%, and 16%, respectively). The first axis represented a gradient of increasing pH and nutrient properties (except for S and P), the second axis was associated with increasing organic matter content (tC), S

and min-N, but decreasing pH and P; and the third axis was negatively associated with the C:N-ratio and positively associated with tN.

The DA using all chemical variables resulted in one significant function, which explained 74.7% of the variance. Mineral soil min-N, SEB, and tN loaded highly positively on this function, and forest floor acidity, tC, and C:N ratio loaded highly negatively. These results agree with the univariate analysis that also showed that mineral soil min-N, SEB, tN and C:N ratios best between discriminated field-identified SNRs.

When the quantitative classification based on measured soil nutrient properties was compared to SNR classes, 55 of the plots (69.6%) fell into the corresponding classes (Table 4.6.2). The two classifications agreed well for the poor and rich plots, with 78% and 76% of the plots being allocated into the corresponding classes, respectively. However, one poor plot was allocated into the class C (corresponding to rich) and one rich site was allocated into the class A (corresponding to poor), indicating disagreement between the two classifications. Medium plots showed the lowest agreement (60%) as 40% of the study plots were allocated into either A or C classes, indicating disagreement between the two classifications. However, the 70% agreement between the two classification methods indicates that both methods generally provide reliable estimates of plant-available nutrients in coastal high-elevation soils.

Table 4.6.2. Comparison of a classification based on field-identified soil nutrient regimes (rows) with a quantitative classification based on direct soil nutrient measures and disriminant analysis (DA) (columns).

DA Assignment	Actual SNR			Total	Agreement (%)
	Poor	Medium	Rich		
Poor	18	4	1	23	78
Medium	9	21	5	35	60
Rich	1	4	16	21	76
Total	28	29	22	79	70

Elevation explained 57% of the variation in Pacific silver fir site index (Eq. 4.6.1), and even the best nutrient-related model (Eq. 4.6.10) only added 12% to the explained variance (Table 4.6.3). After adjusting for elevation, the site index of Pacific silver fir was significantly related to the forest floor, mineral soil C:N ratios (Eqs. 4.6.3 and 4.6.4), tN (Eqs. 4.6.5 and 4.6.6), and forest floor min-N (Eq. 4.6.2), but not to mineral soil min-N. Using both the forest floor and mineral soil tN in a regression equation (Eq. 4.6.7) resulted in a better prediction of site index using either the forest floor or mineral soil tN alone, indicating that both forest floor and mineral soil properties are important.

When the locations of the plots (factor scores) on the axes of the factor analyses for forest floor and mineral soil were used in regression, significant relationships were obtained for the second forest floor factor (Eq. 4.6.8) and for the third mineral soil factor (Eq. 4.6.9). However, the axes explaining most of the variation in soil chemical properties between the plots (factor 1 for forest floor properties, and factors 1 and 2 for mineral soil properties) were not related to site index of Pacific silver fir. The two factors related to site index were highly negatively correlated with the C:N ratios of both the forest floor and mineral soil (for the forest floor factor 2, r = -0.98, for the mineral soil factor 3, r = -0.82), and highly positively correlated with tN (for the forest floor r = 0.96, for the mineral soil r = 0.88). This indicates that organic matter quality (characterized by C:N ratio) and tN alone influence Pacific silver fir height growth.

For the model using the factor scores on both the forest floor factor 2 and mineral soil factor 3 (Eq. 4.6.10), or the combination of forest floor and mineral soil tN (Eq. 4.6.7), the gains in explained variation in site index over the model using only elevation were 11% and 9%, respectively. This indicates that tN captured the majority of the variation represented by the axes of the factor analysis. The regression model with the field-identified SNRs (Eq. 4.6.11) resulted in a gain in the explained variance of 6% over the model using only elevation, approximately equivalent to the models using either forest floor or mineral soil tN.

Table 4.6.3. Statistics of regression models using elevation, soil chemical properties, and factor scores from the factor analyses on the site index of Pacific silver fir. All models are significant ($p < 0.001$, n = 42), all coefficients are significant ($p < 0.05$). ff is forest floor, ms is mineral soil, ELE is elevation, R^2 is the adjusted regression coefficient, SEE is the standard error of the estimate.
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Equation	Regression model	Adj R^2	SEE
4.6.1	SI = 33.215 - 0.015 (ELE)	0.57	4.5 m
4.6.2	SI = 12.935 - 0.017 (ELE) + 4.355 (ln(min-N_{ff}))	0.60	4.3 m
4.6.3	SI = 60.654 - 0.018 (ELE) - 6.505 (ln(C:N_{ff}))	0.65	4.0 m
4.6.4	SI = 40.389 - 0.018 (ELE) - 0.181 (C:N_{ms})	0.66	4.1 m
4.6.5	SI = 33.215 - 0.017 (ELE) + 8.066 (tN_{ff})	0.65	4.1 m
4.6.6	SI = 34.568 - 0.018 (ELE) + 6.336 (tN_{ms})	0.62	4.2 m
4.6.7	SI = 29.029 - 0.019 (ELE) + 7.109 (tN_{ff}) + 5.038 (tN_{ms})	0.67	3.9 m
4.6.8	SI = 43.378 - 0.017 (ELE) + 2.073 (factor 2_{ff})	0.65	4.1 m
4.6.9	SI = 36.672 - 0.019 (ELE) + 2.212 (factor 3_{ms})	0.64	4.1 m
4.6.10	SI = 36.805 - 0.019 (ELE) + 1.630(factor 2_{ff}) + 1.712 (factor 3_{ms})	0.69	3.8 m
4.6.11	SI = 35.246 - 0.015 (ELE) - 5.970 (Poor) - 2.041 (Medium)	0.63	4.2 m

Summary

To quantitatively characterize field-identified SNRs in the coastal high elevation forest and soil nutrient - productivity relationships, soil samples from 79 plots were collected and analyzed for standard nutrient properties. Differences between nutrient properties were somewhat stronger for the mineral soil than for the forest floor, and only a few properties showed significant differences between poor and rich plots. Compared to continental high-elevation soils, maritime high-elevation soils are more acid, have higher C:N ratio, and have higher concentrations of tN but lower concentrations of min-N and SEB. Mineral soil min-N and SEB were the nutrient properties that best discriminated between the medium and rich SNRs, but they were not related to the productivity of Pacific silver fir. Both factor analysis and discriminant analysis indicated weak to moderately strong relationships between soil chemical measures and field-identified SNRs, although these relationships were weaker for medium sites. Generally, the proportion of the variation in fir site index that could be explained by soil nutrient properties on high elevation sites was small compared to that explained by climatic influences. When adjusted for elevation, the field-identified SNRs explained a significant amount of variation in fir site index. Site index was most strongly related to C:N ratio and tN. While the field-estimated SNRs showed only weak to moderate relationships with most soil chemical variables, they captured some significant differences in available nutrients that account for the variation in fir site index in the coastal high elevation forest.

4.7 FOREST PRODUCTIVITY – SITE RELATIONSHIPS

This section is based on Splechtna 1999c.

A knowledge of how climatic, edaphic, and biotic factors affect growth of tree species or how a tree species grows on different sites is essential to site- or ecosystem-specific silvicultural decision-making. The variation in growth or productivity is commonly measured by the site index. Under certain stand conditions, the site index can be estimated directly from measurements of height and age, but when that is not possible it may be estimated indirectly by predictive models using selected ecological measures of site quality. Pacific silver fir is one of the major timber crop species in the coastal forest. Since many extant fir-dominated stands are uneven-aged (especially those in the coastal subalpine forest), indirect methods must be used to estimate site index.

In light of the wide ecological amplitude of Pacific silver fir (see Section 4.5 Height Growth and Site Index Models for Pacific Silver Fir on page 115), elucidation of the influence of climate and soil conditions on the growth of Pacific silver fir requires (1) quantification of the relationships between site index and elevation, continentality, soil moisture and soil nutrients, and (2) the development of site index prediction models based on these measures of site quality. Methods followed those in Section 4.5 for stand selection and measurements.

The relationship between site index and climate (continentality and elevation) was based on a climosequence of 42 stands (on fresh or moist and medium sites, but with varying climate). A hygrosequence (stands with medium SNR, but varying SMR) and a trophosequence (stands with fresh or moist SMRs, but varying SNR) were used to examine relationships between site index and soil moisture and soil nutrients, respectively (Table 4.7.1). Regression analysis was used to examine all relationships between site index and the site. In analysis of covariance (ANCOVA) elevation and continentality were used as covariates.

To develop and test models predicting Pacific silver fir site index, the study stands were randomly split into a calibration data set (67 plots) and a test data set (31 plots). Multiple regression was used to fit predictive models for site index from climate and/or soil variables. Fitted models were tested against the independent data in the test data set. Precision was evaluated by the root-mean square prediction error (the square root of the mean squared differences between predicted and measured site index: root-MSPR), and bias by using paired t-tests. The best model was compared to the climate-specific, polymorphic site index model presented in Section 4.5 Height Growth and Site Index Models for Pacific Silver Fir on page 115.

Covariate analysis using the trophosequence showed an increase of site index with increasing plant-available soil nutrients (mainly nitrogen) ($n = 45$, $p <0.001$). Following Bonferroni's adjustment, multiple comparisons showed that poor sites had significantly lower mean site index than medium and rich sites ($p = 0.008$ and $p < 0.001$, respectively); however, no significant difference was observed between medium and rich sites ($p = 0.176$, Figure 4.7.2). This suggests that the poor SNR represents sites with a nutrient supply insufficient for optimal Pacific silver fir height growth. Consequently, the following edatopes were used for developing the site index prediction model: water-deficient (slightly dry) sites (WD), fresh, nutrient-deficient (poor) sites (ND), and water- and nutrient-sufficient (fresh and moist, medium and rich sites (WNS) (Table 4.7.1).

Pacific silver fir site index decreased with elevation but the decrease varied with continentality (Figure 4.7.1). There was little difference between the maritime to maritime-submaritime transition and the submaritime strata, as for every 100 m increase in elevation site index decreased 2.0 m and 2.4 m, respectively. For the subcontinental stratum, where Pacific silver fir does not occur below 800 m in elevation, the decrease was only 0.8 m for every 100 m increase in elevation. However, for the same elevation site index was much lower in the maritime-submaritime transition and submaritime strata than in the maritime and subcontinental strata. This may be a reflection of drier summers in the maritime-submaritime transition and submaritime strata compared to the maritime stratum, and of a shorter growing season due to higher winter precipitation compared to the subcontinental stratum.

Table 4.7.1. Number of stands sampled according to edatopes (combinations of soil moisture regime and soil nutrient regime). Stands used for the hygrosequence are in bold print, stands used for trophosequence are underlined, and stands on zonal sites (climosequence) are italicized. Boxes refer to three categorical variables used in predictive model (Eq. 4.7.2): water-deficient sites (WD); fresh, nutrient-deficient (poor) sites (ND); and water- and nutrient-sufficient sites (WNS): fresh or moist, medium or rich.

	Poor		**Medium**		Rich	Total
Slightly dry	14	*WD*	**3**			17
Fresh	11	*ND*	***32***	*WNS*	***2***	45
Moist			***10***		***21***	31
Very Moist					5	5
Total	25		**45**		28	98

When adjusting for elevation and continentality, ANCOVA using the hygrosequence showed that there was a significant effect of soil moisture regime on site index (n = 76, $p = 0.02$). Multiple comparisons using Bonferroni's adjustment indicated that the site index on water-deficient sites (slightly dry) was significantly lower than on fresh and moist sites ($p = 0.017$ and 0.034, respectively, Figure 4.7.2). This difference reflects the well-known sensitivity of Pacific silver fir to soil water deficit. No significant difference was observed between fresh and moist sites ($p = 1.0$).
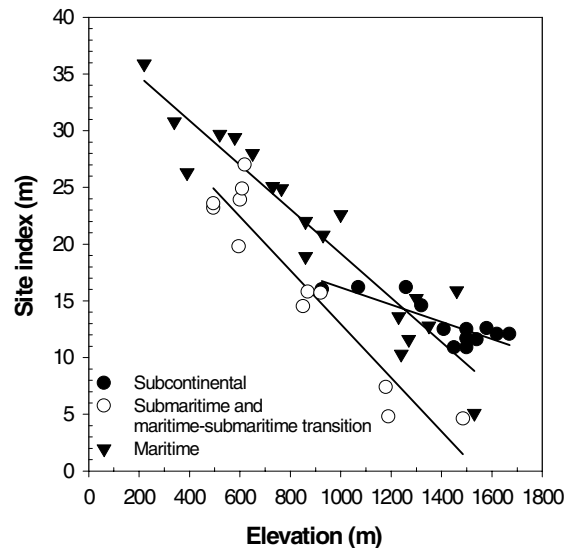
Figure 4.7.1. Regression lines showing the relationship between site index and elevation separately for the continentality strata: maritime ($R^2 = 0.89$), maritime/submaritime transition ($R^2 = 0.89$), and subcontinental ($R^2 = 0.69$). All regressions are significant at $p <0.001$).

a)

b)
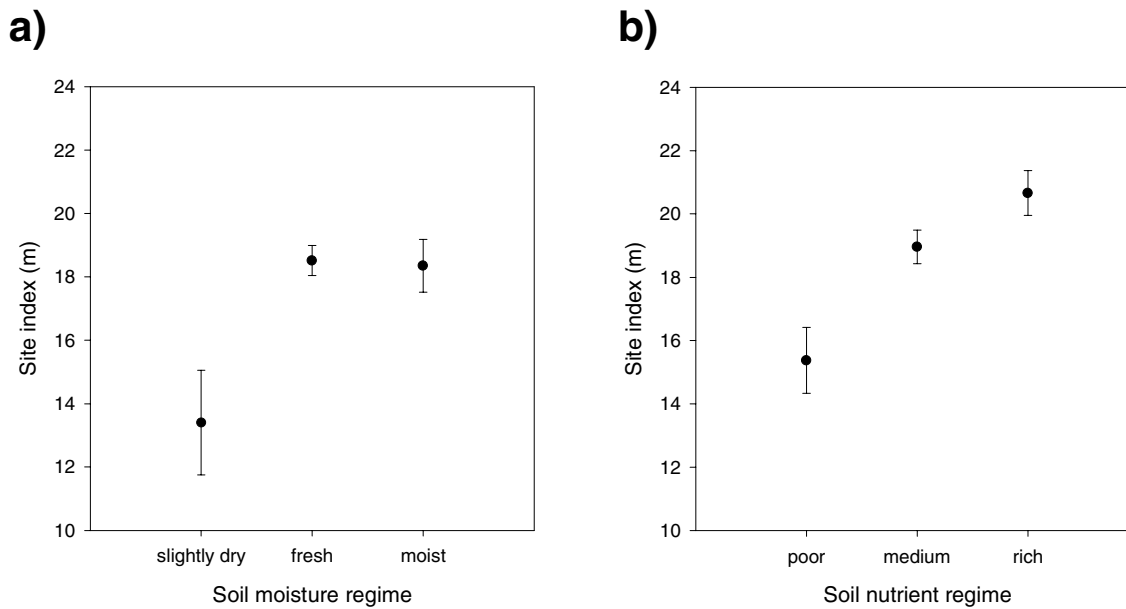
Figure 4.7.2. Relationship of site index to **(a)** soil moisture regimes across a medium hygrosequence (n = 45) and **(b)** soil nutrient regimes across a fresh and moist trophosequence (n = 76) when adjusting for elevation and continentality. Means represent site index at the elevation of 992 m and 969 m, respectively. Error bars represent one standard error of the mean.

The climate model (Eq. 4.7.1) accounted for 78% of the variation in site index but was less precise (higher root-MSPR) than the combined climate-edatope model (Eq. 4.7.2), which explained 84% of the variation in site index (Table 4.7.2). Both models were unbiased when tested against independent data, *i.e.* no significant differences were found using paired t-tests between measured and predicted site index (p = 0.650 and p = 0.795, respectively). The precision of the climate model (root-MSPR = 3.73 m) and of the combined model (root-MSPR = 2.93 m) was low compared to a model using top height, stand age, and continentality stratum as predictors, and which had a root-MSPR of 0.76 m (Figure 4.7.3) (see Section 4.5 Height Growth and Site Index Models for Pacific Silver Fir on page 115). Although unbiased site index estimates for Pacific silver fir can be obtained from these models, their low precision may restrict their application to the forest-level rather than the stand-level.

Table 4.7.2. Models (n = 67) for predicting site index from climate variables (Eq. 4.7.1) and climate and edatope variables (Eq. 4.7.2). R^2 is adjusted for the number of independent variables; SEE is standard error of estimate; root-MSPR is the square root of the mean squared differences between predicted and measured site index using the test data (n = 31); ELE is elevation (m); SC is the subcontinental stratum; M is the maritime stratum; ND and WD are defined in Table 4.7.1.

Equation	Prediction model	R^2adj	SEE	root-MSPR	p
4.7.1	SI = 34.240 - 0.02105(ELE) + 0.01301(ELE×SC) + 6.0(M) - 11.035(SC)	0.78	3.87	3.73	<0.001
4.7.2	SI = 35.783 - 0.02080(ELE) + 0.01202(ELE×SC) + 4.97(M) - 9.852(SC) - 3.313(ND) - 6.047(WD)	0.84	3.12	2.93	<0.001
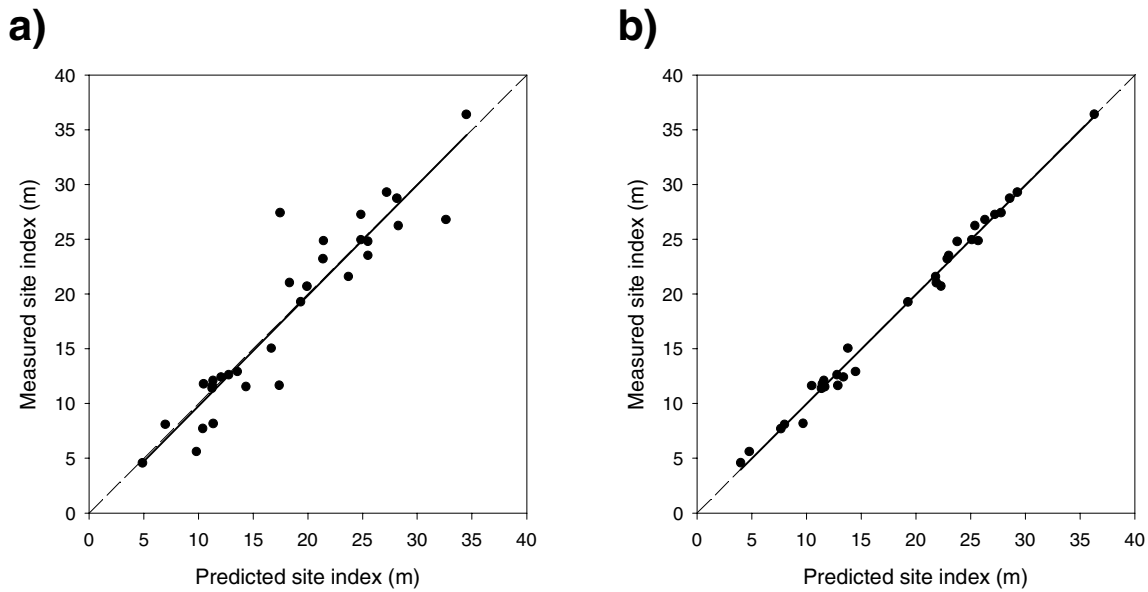
Figure 4.7.3. Scattergrams comparing the predicted to measured (from the test data, n = 31) site index using **(a)** the combined climate-edatope model (Eq. 4.7.2) and **(b)** the climate-specific site index model (Eq. 4.5.2) that used top height and breast height age as well as continentality strata as predictors. Dashed lines indicate perfect correlation.

Summary

Relationships between the site index of Pacific silver fir and elevation, continentality, soil moisture and soil nutrients were examined. As expected, the site index decreased with increasing elevation, but this decrease varied with continentality. Site index was lower on all slightly dry sites and on fresh, poor sites than on fresh to moist, medium to rich sites, where neither moisture nor nutrients were deficient. Both the climate and the combined climate-edatope models had strong relationships with site index (R^2 = 0.78 and 0.84, respectively) but a low precision (MSPR = 3.73 and 2.93, respectively).

4.8 RESPONSES OF TREE-RINGS OF PACIFIC SILVER FIR TO CLIMATIC VARIATIONS

This section is based on Dobry and Klinka (1998).

Climatic influences are reflected in the characteristics of tree rings in regions with discrete growing seasons (Fritts 1970; Briffa *et al.* 1988), and therefore tree rings can be used to predict past climate. However, these relationships have not been studied in the coastal subalpine forest. Tree ring analysis of high-elevation species can provide information on year-to-year climatic fluctuations in the past because growing season temperature is the most limiting factor to cambial activity and consequently ring formation at high elevations (Fritts 1970; Graumlich and Brubaker 1986; Luckman 1997).

Most tree ring studies in the Pacific Northwest were conducted in more continental climates and their applicability to more maritime climates is not known. Several temperature reconstructions were made with varying degrees of success: Graumlich and Brubaker (1986) reconstructed annual temperature from trees at timberline in the Washington Cascades, and Briffa *et al.* (1988) reconstructed summer temperature patterns for the Pacific Northwest.

This study represents the first attempt to investigate which climatic characteristics are related to ring width and maximum latewood density of Pacific silver fir and to reconstruct growing season temperature in coastal BC using ring width and maximum latewood density chronologies. The chronologies were developed from trees growing on a high-elevation site in the transition between the Coastal Western Hemlock and Mountain Hemlock zones in the Capilano Watershed near Vancouver (elevation 1000 m, 49°31' N, 123°04' W). The ring width chronology spanned 307 years, and the maximum latewood density chronology 238 years. The climatic data were obtained from the Agassiz climate station, approximately 100 km east of Vancouver (elevation 15 m, 49°15' N, 121°46' W), where temperature and precipitation had been recorded for 99 years.

Correlations and response functions were used to assess the relationships between climatic variables (mean monthly temperatures and monthly precipitation) and ring width or latewood density. Then a model was developed to reconstruct past growing season (April to September) temperatures from tree ring width and latewood density. The temperatures reconstructed by the model were compared to the temperature reconstructions by Graumlich and Brubaker (1986) and Briffa *et al.* (1988).

Ring width of Pacific silver fir correlated negatively to the July temperature of the previous year, and showed significant positive responses to the August precipitation of the previous year and the May precipitation of the current year, and negative responses to the July precipitation of the current year. Maximum latewood density showed significant positive responses to the March, April, May and August temperatures of the current year and significant negative responses to the November precipitation of the previous year and the September precipitation of the current year (Figure 4.8.1).

The significant negative correlation between July and August temperature of the previous year and ring width of the current year is consistent with the results of Ettl and Peterson (1995) and Garfinkel and Brubaker (1980). A possible explanation for the significance of the previous year's late summer temperature is that low temperatures reduce foliage loss during late summer moisture stress and cause the trees to allocate stored assimilates for use in the next growing season, thus positively affecting ring width (Larsen and MacDonald 1995).

Based on climatic observations, it appears that annual radial growth is affected less by temperature than by precipitation. A lower March precipitation (probably a lower late snowfall), higher May precipitation (likely decreasing the snowpack due to rainfall), and lower July precipitation provide favourable conditions for radial growth of high-elevation Pacific silver fir.
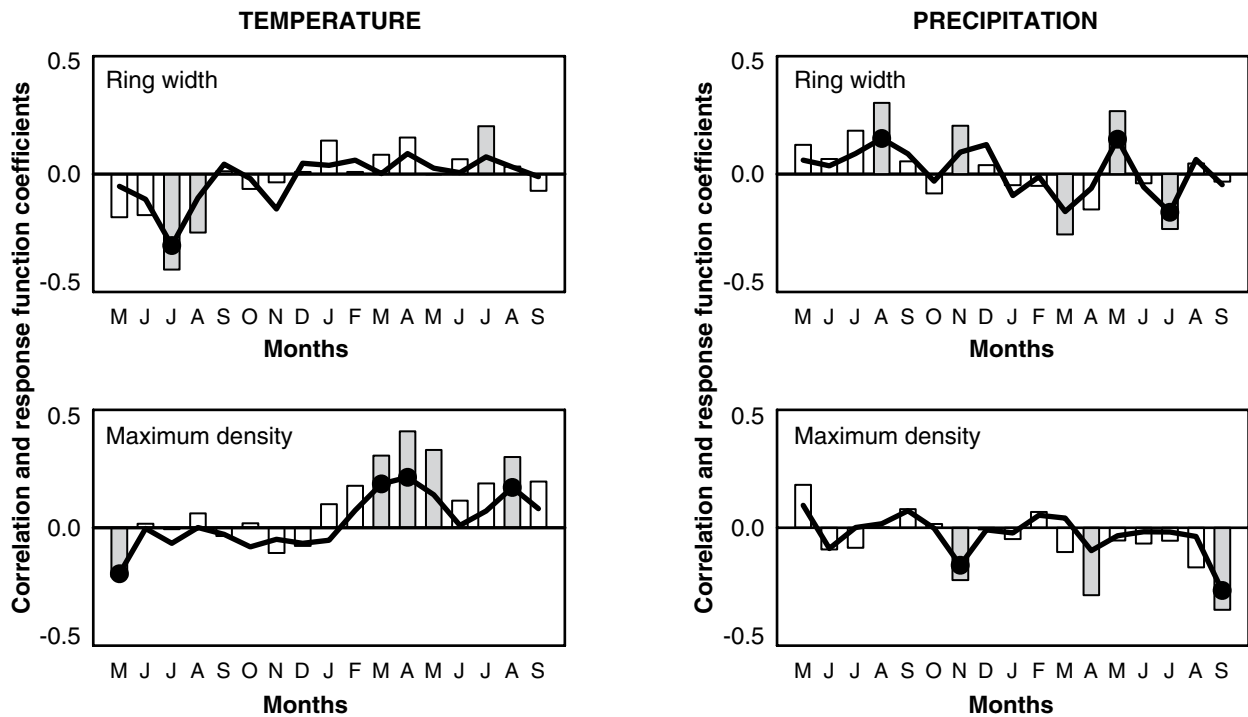
Figure 4.8.1. Relationships between indices of ring width and maximum latewood density chronologies for Pacific silver fir and mean monthly precipitation and temperature (May of the previous year to September of the current year) for a period of 99 years represented by correlations (bars) and response functions (lines). Months with significant positive or negative relationships between climate and ring width or maximum latewood density indices are denoted by filled bars or circles, respectively.

It appears that temperature has a stronger influence on latewood density than precipitation (Figure 4.8.1). A high spring temperature of the current year, which is conducive to faster snowmelt, and high late summer and early fall temperatures result in a longer growing season. This provides sufficient time for the formation of high-density latewood. Also taking into account also negative responses to spring and early fall precipitation, we suggest that a dry and warm spring and late summer provide the most favourable climatic conditions for the formation of high-density latewood in Pacific silver fir.

Since ring width and latewood density are related to temperature, these variables were used to reconstruct past growing-season temperatures. The low-frequency component (which removes some of the short term variation) of the reconstructed temperatures for the 1770 - 1990 period had the same mean as the original data, and showed alternating periods with predominantly higher or lower reconstructed temperatures (Figure 4.8.2). Similar fluctuations of past temperatures were also reconstructed from tree rings for other areas of the Pacific Northwest were also reported by Graumlich and Brubaker (1986) and Briffa *et al.* (1988), which illustrates the large geographic scale of tree growth patterns related to climatic changes.
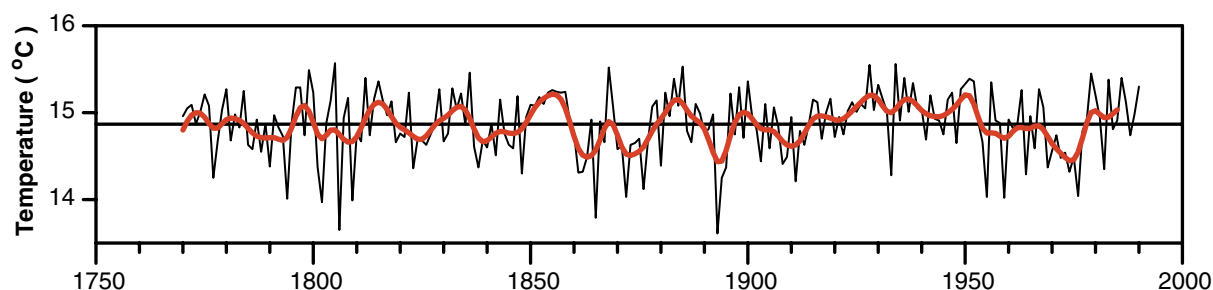
Figure 4.8.2. Reconstruction of the mean April to September temperatures over the 1770-1990 period for Vancouver, BC. The smoothed line is for the same data passed through a 13-yr low-pass filter.

These results show that even on the same site radial growth of trees and wood properties are not uniform over time, but vary with temperature and precipitation patterns, which occur in irregular cycles of one or more decades.

Summary

Tree-ring-width and maximum latewood density chronologies for high-elevation Pacific silver fir near Vancouver, BC were used to determine the growth response to climate and to reconstruct the mean April to September temperatures for the 1770 - 1990 period. Annual radial growth increased with decreasing March and July precipitation and with increasing May precipitation of the current year. Maximum latewood density increased with increasing spring and late summer temperature and decreasing late summer precipitation of the current year.

5 RESOURCE MANAGEMENT AND SILVICULTURAL IMPLICATIONS

5.1 INTRODUCTION

The coastal subalpine forest is an ancient forest and a major feature of the spectacular landscape of coastal British Columbia. The forest has been used as a timber resource since the 1960s and a large area has been cut despite concerns about disturbing the ecology and uncertainties regarding the feasibility of managing the forest for timber production, appropriate cutting methods and patterns for regenerating the forest.

Concern over the poor regeneration on cutovers in the MH zone began in the early 1970s. The interim guides for harvesting on severe sites (Gilmour 1973) recognized the need for a site-specific approach, pre-harvest examination and research. Since that time, the magnitude of the problem has been determined and the effects of practices such as slashburning, rapid removal of the tree canopy, and the inappropriate planting of Douglas-fir on regeneration, soil stability and productivity have been examined (Reuter 1973; Utzig and Herring 1975; Von Hahn 1975; Herring and Etheridge 1976). Klinka and Pendl (1976) re-emphasized Gilmour's (1973) conclusions and proposed a research program in support of high-elevation forest management. They also identified the types of stands or sites that should not be disturbed. In response to their problem analysis, site-specific tree species selection and slashburning guidelines were developed (Klinka 1977; Klinka *et al.* 1984; Banner *et al.* 1993; Green and Klinka 1994) and high-elevation species and stock type trials were carried out (Arnott *et al.* 1989; Scagel *et al.* 1989; Arnott1991; Arnott and Pendl 1991).

Despite these efforts, much of the current silvicultural decision-making in the MH forest is still based on limited and relatively recent experience rather than on an adequate understanding of the ecosystems. Before viable management options can be proposed and rationally evaluated, and special policy, goals, and strategies for protecting forest productivity can be advanced, extensive knowledge of the factors controlling forest establishment and growth is needed. While several ecological investigations carried out in the MH zone (*e.g.*, Brooke *et al.* 1970; Yarie 1978; Krumlik 1979; Martin 1985; Lertzman 1989; Scagel *et al.* 1989; Splechtna 1999a) have provided some of the desired information, many aspects of the ecology and dynamics of the MH zone forest remain poorly understood.

This chapter compiles and interprets the existing information. A brief history of harvesting in the MH zone, some of the resource management issues and concerns, and the areas requiring further investigation and focus will be presented and discussed.

Sections 5.1 through 5.8 and 5.10 are based on Klinka et al. 1992; Section 5.9 is based on Brett 1997c.

5.2 MANAGEMENT AND OPERATIONAL BACKGROUND

To date, the timber supply role of the MH zone has been determined entirely by economics, perceived necessity, and through the inclusion of many stands in the inventory of operable timber. As these stands may contain large standing timber volumes, they have been made available to alleviate a regional shortage in timber supply. Given the low number of remaining low-elevation old-growth stands, licencees are relying on the removal of subalpine old-growth stands to maintain allowable cuts until low-elevation second-growth stands become operable. A strategic analysis of sustainable timber supply for the MH zone can not be done, as there is no growth and yield data for the MH zone. To suggest that these stands be managed differently than low-elevation stands would require a significant change in outlook by current managers and users of the forest resource.

For administrative purposes, stands in the MH zone fit into two categories. Stands of the first category are included in the annual allowable cut (AAC). This category includes operable stands (*i.e.*, stands of sufficient volume, quality, and accessibility to afford an economic operation) that have not been set aside for other uses such as wildlife, visual quality, recreation or parks. Stands of the second category are known as 'opportunity wood'. This category includes all stands that are not considered operable or set aside for other uses. These stands are not included in the AAC calculation, but they are often harvested when markets make it economically attractive. This is particularly true of low-volume Alaska yellow-cedar stands with costly access that are cut during good markets. The economic value of stands in this second category should not be underestimated.

Under the current policy, operable stands in the MH zone are included with all other submontane and montane stands in the AAC determination. This approach appears to have discouraged consideration of specific MH zone during planning activities. As a result, it is expected that there will be serious age-class imbalances in the MH zone with harvesting activities intensifying over the next 20-30 years, followed by little harvest activity and an extensive immature forest. The use of smaller "working circles" (natural geographical units such as watersheds) rather than the large timber supply areas might be more appropriate when actively managing this zone. This might lead to a better balancing of age-classes and improved configuration and size of cuttings - all prerequisites for preservation of the diverse mosaic of stands necessary for maintaining production of timber crops, other values, and community stability. However, the goals of forest management are not explicit at the moment.

The coastal subalpine forest has been cut almost exclusively using clearcuts, cable harvesting systems, and conventional road construction techniques. It seems that little thought has been given to cutting, access, and other uses of the forest. In fact, long-term land use planning seems to be sporadic or absent. Due to steep terrain and large timber, the use of cable harvesting systems has been the logical primary mode of transport. Occasionally the use of grapple-yarders has resulted in unsightly and non-reforestable road-side accumulations of non-merchantable woody debris. Ground-based equipment has been very infrequently used, and, while its use is appropriate in some situations, it is limited by terrain characteristics.

There seems to be no clear access policy. Under present conditions, operating areas in the MH zone are being abandoned when they have achieved free-to-grow status or when access has been lost due to road failures and washouts. Many roads appear to have been built for short-term access only. Furthermore, they have not been properly 'put-to-bed', and are without adequate structures to control runoff. In many situations, inadequate end-hauling was carried out resulting in loss of productive soil or, in some cases, slope failures due to over-loading of surface materials. This often occurred in combination with poor control of subsurface seepage water. Most slope failures could be avoided through improved use of terrain stability assessment and better control of surface and subsurface drainage (*e.g.*, avoidance of mid-slope roads on unstable terrain through greater use long-line harvesting systems, outsloping of roads, water bars, and more and larger culverts).

As the most productive sites are seepage (Twistedstalk) sites (Brooke *et al.* 1970), any severe disturbance of subsurface seepage water flow, such as that caused by a dense, ineffectively drained network of roads on long slopes, may decrease forest productivity (Klinka and Krajina 1986). This occurs when seepage flow is intercepted by a roadcut and channeled via the road ditches into a few culverts, depriving much of the slope from water and dissolved nutrients.

Summary

The coastal subalpine forest has been used as a timber resource but there are no special policies, strategies, or goals once the free-to-grow requirement has been achieved. Low-elevation operational practices have been extended to the MH zone with little modification, showing that not enough thought has been given to its special characteristics and inherent values, its slow recovery after disturbance and the high and prolonged visibility of cutovers. More knowledge and planning is necessary to maintain site productivity and to ameliorate road-induced mass wasting.

5.3 THE DECISION TO HARVEST OR NOT TO HARVEST

Cutting the coastal subalpine forest is part of a strategy to bridge the timber supply gap during the transition from old-growth to second-growth submontane and montane forests. At the same time there is increasing pressure to recognize and protect non-timber values. The historical argument is that the 'present value' approach identified these stands as having timber values that are overwhelmingly greater than non-timber values, and that they should therefore be harvested. However, this same approach would also find that returns made on investments to regenerate and manage these sites for a second-growth crop are poor relative to opportunities in low-elevation forests.

Ultimately, the decision to harvest or not will have to be based on a combination of biological, ecological and economic criteria that will involve negotiation and compromise. If this debate is to find an optimal or even acceptable solution, it is essential that we develop an understanding of the many inter-relationships involved. Perhaps the most important factor is the consideration that forest productivity sharply decreases with increasing elevation (snowpack) to near zero in the upper limits of the MH zone. (*e.g.*, Brooke *et al.* 1970). Consequently, there must exist a point at which the potential growth and form of trees and operational difficulties create conditions that are not conducive to the viable production of timber crops.

As the MH zone has a wide range of ecological and structural attributes and values, management decision-making will have to be site-specific. In their undisturbed state, the relatively stable subalpine communities can offer many benefits. These include: high quality visual landscape values, recreation opportunities, a unique habitat for many plant and animal species, control of snowmelt and water storage. In deciding whether to harvest MH stands it will be essential to determine the benefits accruing from these values, the ability of the site to recover, the effort required regenerate the site following disturbance, and the time required for the established stand to mature.

In general, operations in the MH zone can be characterized as being costly. This is the result of (i) the need to develop and maintain access and associated infrastructure, (ii) difficult terrain, (iii) low volumes per hectare, (iv) large losses to decay, waste and breakage, (v) inefficient transport, and (vi) a short operating season. The economics of harvesting operations has been improved through the use of cutting patterns based primarily on large and relatively continuous clearcuts. This pattern minimizes yarding costs and offers the greatest pay-back for road development and maintenance.

One can use legal and ethical criteria to determine whether particular stands should be cut, and to choose the most appropriate methods of cutting and harvesting. As the agency responsible for the management of the forest resource, the BC Ministry of Forests has a well-defined purpose supported in law. As stated under the 1997 Ministry of Forests Act (Bill 12, article 5), the "purposes and functions of the Ministry are, under the direction of the Minister, to do the following

(a)   encourage maximum productivity of the forest and range resources in British Columbia
(b)   manage, protect and conserve the forest and range resources of the government, having regard to the immediate and long term economic and social benefits they may confer on British Columbia"

To fulfill this mandate the Ministry requires that the individual or company with harvest rights carry out specific forest and stand level planning activities, secure approved cutting permits, and meet prescribed standards for regeneration and "free-to-grow" surveys. Submission and acceptance of these legal documents requires the signature of a Registered Professional Forester.

Registered Professional Foresters, in turn, have their own standards. The Code of Ethics of the Association of BC Professional Foresters (Bylaw 14, 1996) states that, "**14.3**. The responsibility of a member to the public is

(14.3.1) To advocate and practice good stewardship of forest land based on sound ecological principles to sustain its ability to provide those values that have been assigned by society;
(14.3.2) To uphold professional principles above the demands of employment;.
(14.3.3) Where a member believes a practice is detrimental to good stewardship of forest land:
     (14.3.3.1) To advise the responsible person promptly and if the matter is not resolved, to inform Council immediately in writing of the particulars; or
     (14.3.3.2) If it is not possible to raise the matter with the responsible person or it is inappropriate in the circumstance to do so, to inform Council immediately in writing of the particulars; To advocate and practice good stewardship of forest land based on sound ecological principles to sustain its ability to provide those values that have been assigned by society;
(14.3.4) To work to improve practices and policies affecting the stewardship of forest land;
14.3.5) To work to extend public knowledge."

These two statements, and their associated legislation, define the legal and professional criteria that together should lead to an acceptable standard of forestry practice in the MH zone. Society has the expectation that these legal and ethical statements will be maintained in such a way that the standards they address will reflect the best available information and current societal values. When this expectation is fulfilled it is assumed that conservation values are being properly addressed. Conservation criteria can then be married with present value criteria and the best use for the forest can then be determined.

It is clear that our current knowledge of the MH zone is inadequate for entirely knowledge-based decisions; however, our understanding is at a level that allows us to make rational decisions. If the assumption is made that the use of, and operation in, the MH zone will

1. meet or exceed all current legislated and ethical standards of practice (in order to accommodate conservation criteria);
2. have a positive contribution to present values; and
3. be followed by successful regeneration of the forest crop and recovery of ecological values within a time-frame dictated by current legislation;

then it appears that not all stands should be cut or are best suited for timber production. However, it should be possible to categorize the stands according to their value as a timber resource using present value criteria (*e.g.*, their suitability for timber production: timber values, operability, silvicultural liabilities, etc.), and conservation criteria. This will likely lead to a zoning into three classes:

1. Suitable - stands where clearcutting (*e.g.*, medium-size (10-30 ha) clearcuts with a defined minimum of green-up and adjacency restrictions) is a feasible harvest option. Such stands will be located on sites with a relatively high resilience, where timber values are sufficient to provide for an economic operation, and the impact on conservation values is acceptable.
2. Marginally suitable - stands on sites where some modification of current harvesting practices will be required (*e.g.*, small-size clearcutting (1-10 ha), as patch-cutting, or strip-shelterwood cutting, long-term adjacency constraints, extended rotation lengths, etc.).
3. Unsuitable - stands unsuitable for cutting and/or timber production (see Klinka and Pendl 1976).

Management planning for stands in Class 1 to the standards currently required in law will require the collection, analysis, and interpretation of a significant amount of new information. The first priority is identification of the ecological basis for recognition of sites and stands in this class. Most stands of this class will be relatively close-canopied, "even-sized" in appearance, and will be found in the lower portion of the forested subzone. Regeneration planning will require that decisions regarding cutting layout be based on a better understanding of the requirement for, and availability of, protection provided by adjacent stands in relation to seed source, prevailing winds, and the duration and depth of the local snowpack. Information will also be required to

determine the importance and availability of natural regeneration, vegetation control and appropriate expectations for the regeneration delay and the time required for free-to-grow status. At the present time it appears that much of the concern over the timeliness of regeneration establishment through crown closure stages of stand development is due to the bias of foresters whose experience and perceptions originated primarily in the low-elevation forest.

Finally, if stands in Class 1 are truly to be managed for successive forest crops while conforming to the requirement for maintaining long-term site productivity, improved forest productivity information is required. As with forests in virtually all biogeoclimatic zones, efforts aimed at identifying non-timber values across the stand, forest and landscape levels will have to begin.

Management planning for stands in Class 2 will require clearly defined goals that identify what is to be achieved, and strategies to achieve these goals within the imposed constraints. Regeneration planning for these stands will require modification of harvest techniques to provide (i) feasible regeneration, (ii) acceptable windfirmness of the residual stand and adjacent stands, (iii) minimization of soil degradation and damage to subsurface drainage, (iv) protection of watershed and other values, and (v) acceptable visual quality.

Many of the stands that will be placed in Class 2 will likely have marginal present values under current management scenarios. Imposition of further restrictions on reproduction method and rate of cut will likely make operations in many of these stands uneconomical although their role in providing a satisfactory, but incremental, flow of timber to manufacturing facilities may justify their harvest. While there appear to be several silvicultural solutions available for reducing the impact of cutting for stands in this class (*e.g.*, smaller clearcuts, shelterwood cuttings, both with retention of large, low-value non-crop veterans for protective cover and as 'wildlife' trees (Lousier 1990), and harvest rate restrictions). However, study of these silvicultural options should be given a lower priority than work aimed at identifying and examining:

1. methods of recognizing stands in Class 2 and classifying the basis of their requirement for modified practices, and
2. the economics of current cutting operations according to general strata identified above, and the probable effects of modifications of current practice on the operability of these stands.

This work will not likely require detailed information on costs and volumes associated with non-clearcutting reproduction methods. A simple model examining the current profitability of harvesting operations in Class 2 stands and a sensitivity analysis examining the effects of differing levels of reduction in operator efficiency and increased costs associated with road development and maintenance should be adequate to provide a general picture of opportunities for using silvicultural solutions.

The magnitude of changes to the operable forest land base in the MH zone made as a result of the classification proposed above is unknown. Due to the significant current cutting pressures on the forest, it appears to be imperative that a basis for recognizing the best use for each stand and forest be developed. In the interim period, it appears to be most appropriate that a conservative approach be taken, which will undoubtedly result in some reduction in the current level of harvesting activities in the MH zone.

Summary

There are biological, operational, economical, and social limits on the ability of the coastal subalpine forest to produce timber crops, which implies that there is a limit to the cutting of old-growth MH stands. The existing legal and ethical criteria and knowledge level allows us to make rational management decisions provided that changes and improvement in the decision-making and planning process on stand, forest and landscape levels are made. In the interim period, we recommend that a conservative management approach be adopted and that classes of stands, where different levels of operation are permitted, be identified.

5.4 THE IMPACT OF CUTTING ON TIMBER AND NON-TIMBER RESOURCES

There is no policy attempting to sustain the yield of operable stands in the MH zone. They are currently included in the AAC scenarios together with stands in the CWH zone, which is leading to liquidation of these stands. Unless changes are made, we estimate that the remaining operable stands will be cut in the next 40 years. However, extensive harvest through the use of clearcutting may contravene the present perception of values found in the MH zone, and may be found to be socially unacceptable and lead to confrontations.

We are convinced that nearly all cutover sites will be satisfactorily regenerated naturally, with the aid of planting on some sites. Once these sites have achieved free-to-grow status, there will be no apparent reason to justify the expense of maintaining extensive road networks on steep mountain slopes as it may take 30 to 60 years after cutting for the regeneration to reach crown closure and to develop into the stem exclusion stage. As a consequence, many of these lands will become inaccessible by roads that will be lost due to washouts or failures. This loss of access will tend to prohibit tending operations in these stands.

Assuming that canopy closure will occur with no stand tending, we predict that the next phase in stand development, lasting for approximately the next 50 to 150 years, will feature a predominance of dense, clumpy, Pacific silver fir-dominated stands with poor structural differentiation. Low light levels and cool humid microclimates under the closed tree canopies of these stands will severely suppress the development of understory vegetation, restricting all but the most shade-tolerant bryophytes. This condition will contrast strongly with the medium to high cover of ericaceous shrubs in the understory of old-growth stands. If left untended, the following 'understory initiation' phase of stand development may extend for the next 100 to 300 years before sufficient structural differentiation to allow the formation of a well-developed understory will occur.

If a large part of the landscape is in this long-lasting understory initiation stage, this will affect both the present and future timber and non-timber resources (watershed, wildlife, scenic and recreation), as well as biodiversity. However, the potential impact of this situation on all resources across the stand, forest and landscape levels needs to be examined and quantified.

Summary

The current timber supply shortage in southern coastal British Columbia and the lack of a provision for a sustained harvest in the climatically constrained forest of the MH zone will unavoidably lead to the liquidation of operable and 'opportunity wood' stands and to the loss of road access in the near future. The development of second-growth stands following clearcutting will occur over a long period of time, and unless tended, they will likely be species-poor, simply structured, and of low diversity. Tending operations are unlikely due to access limitations and expense on steep, rugged terrain. The large extent and lower structural diversity of these stands will affect both the present and future resource values.

5.5 STANDS PROPOSED TO BE EXCLUDED FROM HARVESTING

Taking into account the low productivity, high site sensitivity, and/or regeneration difficulties, we consider the following stands/sites unsuitable for timber production and recommend that they remain undisturbed.

1. Tree-islands in the true climatic MH parkland

In the parkland, the potential of snow damage is high and young trees require the protection of the larger trees in the tree islands. The following two pictures illustrate tree islands in the lower parkland. While the productivity and the vigour of the trees is higher in lower parkland and the distance between tree-islands is smaller than in the upper parkland, the canopy is still open and the tree-island pattern is still present (Figure 5.5.1).

Figure 5.5.1. Distant and close-up views of tree-islands at the lower elevation limit of the true climatic parkland.

2. Tree-islands in the topographically induced MH parkland

The topographically induced MH parkland is a complex of tree-islands and predominantly non-forested wetland communities on flat terrain within the forested subzones (Figure 5.5.2, also see Section 3.2 ZONAL CLASSIFICATION - Zonation and Climatic Localisms on page 26). Regeneration difficulties are similar to those of the true climatic parkland shown on page 140.

Figure 5.5.2. Distant and close-up views of topographically induced parkland on flat sites within the forested MH subzones at lower elevations.

3. Rock outcrops on exposed ridges, crests, and hilltops

The size of rock outcrops is variable and they are commonly interspersed with other sites in a complex pattern. Exposed bedrock faces are often covered by a shallow organic layer rich in decaying wood (Figure 5.5.3). The stands on rock outcrop sites typically have a semi-open or open canopy and are subjected to recurring windthrow. Regeneration after clearcutting is often very slow or absent (Figure 5.5.4).

Figure 5.5.3. This stand on a large rocky hilltop was excluded from cutting (Sechelt Penninsula) – perhaps a larger area of forest should have been preserved.
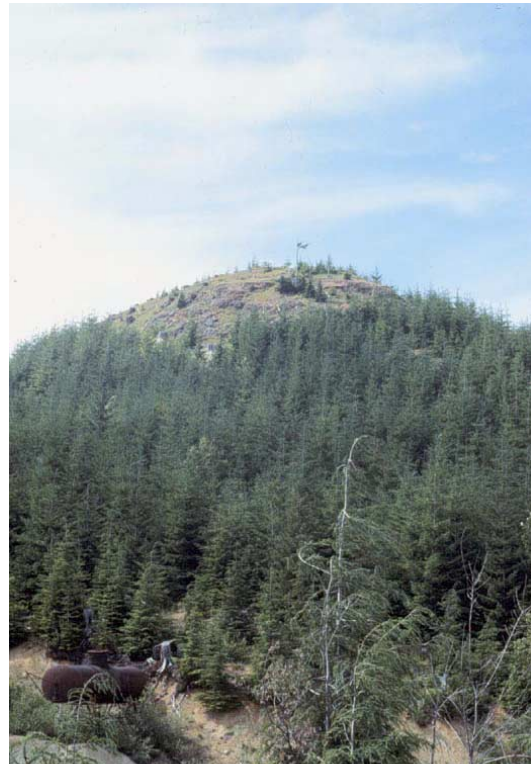
Figure 5.5.4. Approximately 20 years after the entire area was harvested, this subalpine rock outcrop (on the hilltop) has not regenerated.

4. Stands on steep-rocky sites

Stands on steep-rocky sites have not yet been explicitly recognized as a special site association in any biogeoclimatic zone. Tentatively, we treat these sites as part of the ecologically most closely related site association, usually the zonal site association (Figure 5.5.5). The actual SMR varies depending on climate, the relative SMR ranges from 2 through 4, and the SNR from very poor to medium. Clearcutting results in soil erosion and it is difficult to regenerate these sites by planting or ingress (Figure 5.5.6).

Figure 5.5.5. A stand on a steep-rocky site that should not be disturbed.

Figure 5.5.6. Clearcutting on this steep-rocky site has resulted in soil erosion and regeneration problems.

5. Stands on wet-slope sites

Wet-slope sites are common in high-precipitation climates and occur on slopes >30%. They feature seepage and either very moist (the depth of the growing-season water table is between 30 and 60 cm) or wet (the depth of the growing-season water table is between 0 and 30 cm) soil moisture conditions (Figure 5.5.7). These sites potentially have high soil instability and are susceptible to mass wasting (*i.e.* landslides) (Figure 5.5.8).

Figure 5.5.7. Seepage on a wet-slope site. Its proximity to the ground surface makes this site prone to mass-wasting.

Figure 5.5.8. Mass wasting on a steep, wet-slope site.

6. Stands on fragmental sites (talus) with <50% forest cover

Ecosystems of fragmental sites have not yet been explicitly recognized as a special site association in any biogeoclimatic zone. Tentatively, we treat these sites as part of the ecologically most closely related site association. Depending on the climate, the SMR ranges from 2 to 5 and the SNR ranges from medium to rich.

When deciding whether or not to harvest stands on fragmental sites, it is necessary to determine whether the forest community is in the early, mid-, or late stage of primary succession. In the early stage of succession the talus is non-forested, in the mid-stage Alaska yellow-cedar and/or subalpine fir function as pioneer species, with Alaska yellow-cedar reproducing predominantly by layering (Figure 5.5.9); the final stage is recognizable by a more or less closed forest canopy (Figure 5.5.10). Late successional stands on fragmental sites with <50% forest cover will never be fully stocked and should not be disturbed.

Figure 5.5.9. Alaska yellow-cedar reproducing by layering on a fragmental site.
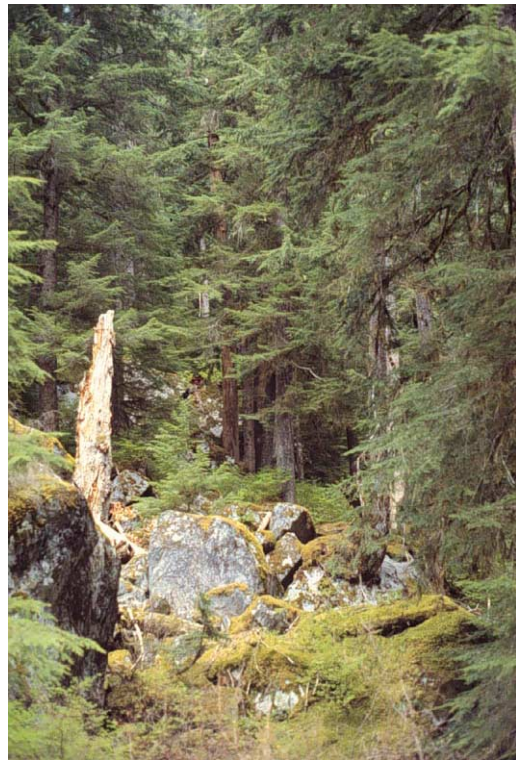
Figure 5.5.10. Open-canopy western hemlock/Pacific silver fir stand on a montane fragmental site (Seymour watershed).

7. Stands adjacent to avalanche tracks

Avalanche tracks are the result of the rapid down-slope movement of snow masses and can extend from the AT, through the MH and into the CWH zone. Depending on the frequency and intensity of avalanches, avalanche track sites support various plant communities in different stages of primary succession. Active (*i.e.*, recently formed or frequently disturbed) avalanche tracks feature exposed bedrock and mineral and organic debris (Figure 5.5.11), while inactive avalanche tracks support well-developed non-forested communities (Figure 5.5.12). Stands bordering avalanche tracks help to contain the lateral spread of avalanches and their removal will likely result in an increase in non-forested communities. Regenerating these areas is not a feasible option.

Figure 5.5.11. Active avalanche tracks featuring exposed mineral soil and organic debris.
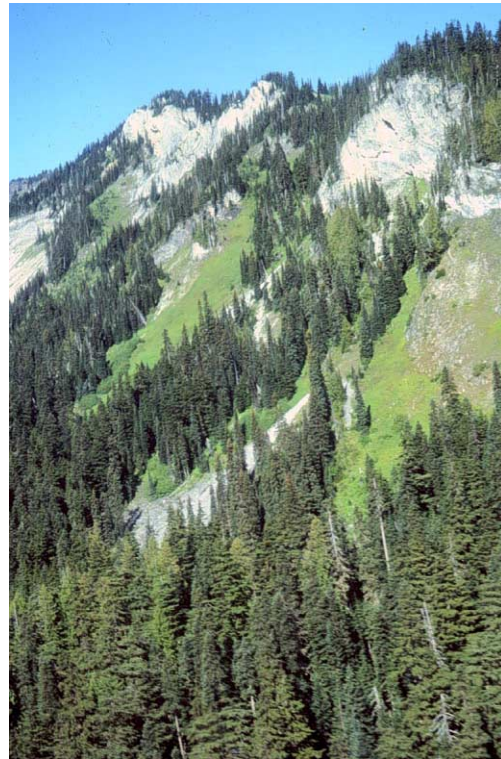
Figure 5.5.12. Inactive avalanche tracks supporting well-developed non-forested communities.

8. Stands adjacent to large streams

Stream edge sites can border steep (Figure 5.5.13) or moderate gradient (Figure 5.5.14) streams, and support communities of either hardwoods (*e.g.*, Sitka alder) or softwoods (*e.g.*, Alaska yellow-cedar, Engelmann spruce or subalpine fir). The removal of stream-edge stands may disturb riparian areas, cause bank erosion and disrupt the input of coarse woody debris into the stream.

Figure 5.5.13. Engelmann spruce/subalpine fir community bordering a steep-gradient stream.
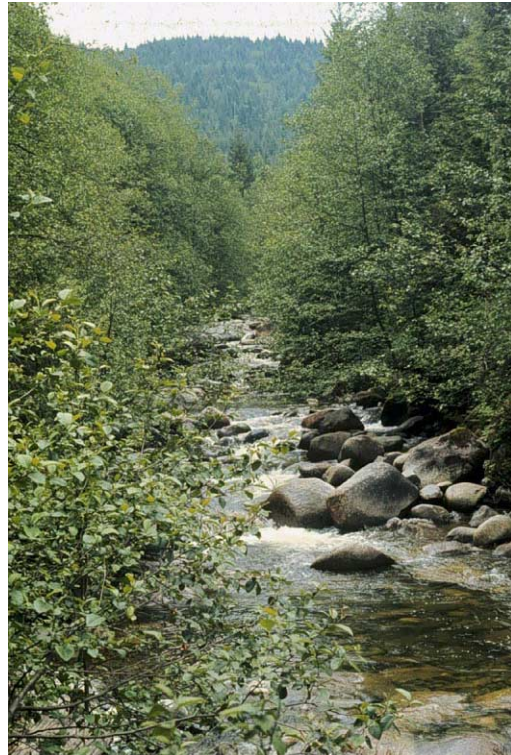
Figure 5.5.14. This disturbed moderate-gradient stream-edge sites supports a Sitka Alder community.

9. Stands on wet sites

Stands on Sphagnum (poor) and Skunk Cabbage (medium and rich) (Figure 3.5.39) sites are often marginally productive. Waterlogged Sphagnum sites extend from low to high elevations (Figure 5.5.15). The proportion of Alaska yellow-cedar and mountain hemlock increases with increasing elevation. Following a major disturbance, a hydrosere succession begins from sphagnum or graminoid to ericaceous communities, and finally to lodgepole pine communities. Wet sites can contain sizeable non-forested communities and have a semi-open or open canopy. Considering the very slow growth rates and low productivity these sites should not be disturbed.

Figure 5.5.15. A nutrient-poor Sphagnum site dominated by Alaska yellow-cedar and mountain hemlock.

5.6 TREE SPECIES OPTIONS

There are only three major tree species in the MH zone: mountain hemlock, Pacific silver fir (except on the Queen Charlotte Islands), and Alaska yellow-cedar, which has a low frequency compared to other biogeoclimatic zones. All three species, especially Alaska yellow-cedar, occur across a wide range of sites and along the whole successional gradient; *i.e.*, there are no 'pioneer' species that occupy only disturbed sites. Mountain hemlock is less vigorous on wet sites; Pacific silver fir is less common and vigorous in the upper limits of the zone and on water-deficient and wet sites. The driest (scree and talus) and wettest sites often support pure Alaska yellow-cedar stands. It appears that on intermediate sites the growth performance of the three species is about equal. However, the early height increment of Pacific silver fir on water-deficient sites was observed to be quite erratic (Husted 1982). Alaska yellow-cedar consistently displayed rapid, albeit highly variable, juvenile growth on a wide range of sites.

Examination of old-growth stands across a wide range of sites in the MH zone suggested some variation in tree species composition. However, any of the sites may be dominated by mountain hemlock, Pacific silver fir, or, infrequently Alaska yellow-cedar; with mountain hemlock/Pacific silver fir mixtures being most common. Other mixtures such as mountain hemlock/Alaska yellow-cedar, Pacific silver fir/Alaska yellow-cedar or mountain hemlock/Pacific silver fir/Alaska yellow-cedar are less common. The reason for this pattern is not well understood, and growth and yield data are not available to determine definitively which species, or combination of species, is most productive. We think that Pacific silver fir-dominated stands will be more productive in terms of volume than other stands because of the low taper, thin bark, and shade tolerance of the species, which result in higher basal area/ha, although Alaska yellow-cedar is far more commercially valuable than the other two species. Based on the composition of natural stands, we suggest that any of the three aforementioned species can grow successfully in any combination as major or minor species on a wide range of sites in the MH zone.

Five other species that are most common in areas adjacent to the MH zone could be grown in the MH zone, albeit with some restrictions. These are: Sitka spruce (*Picea sitchensis*), Engelmann spruce (*Picea engelmannii*), noble fir (*Abies procera*), subalpine fir (*Abies lasiocarpa*), and western white pine (*Pinus monticola*).

Mountain hemlock

Mountain hemlock grows in pure stands (Figure 5.6.1) or in mixtures with Alaska yellow-cedar or Pacific silver fir (Figure 5.6.2). Almost all the mountain hemlock stands we observed had some recruits in the understory in areas with sufficient light and some disturbance of the ground surface. Under low light conditions, regeneration was less common on the forest floor and was limited to downed woody debris. Also, the surviving regeneration had often lost its apical growth and potential for release. This suggests that mountain hemlock is less shade tolerant than Pacific silver fir and Alaska yellow-cedar, and that its regeneration benefits from forest floor disturbance. We do not think that well decomposed, large woody debris is necessarily a preferred substrate for germination as implied by Vogt *et al.* (1989) and Christy and Mack (1984). Disturbed or friable forest floor materials are recommended planting substrates (Klinka *et al.* 1990b). Response of advance regeneration to release is similar to that described for Pacific silver fir.
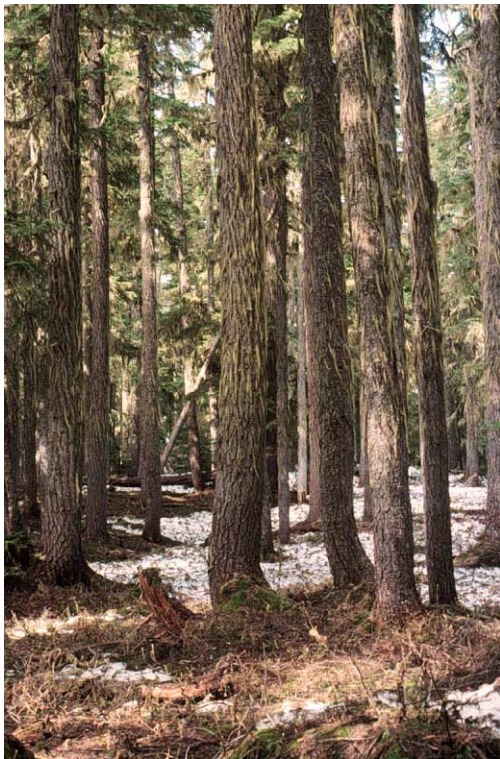
Figure 5.6.1. Pure mountain hemlock stands are infrequent, but not rare.

Figure 5.6.2. Mountain hemlock/Pacific silver fir mixtures, such as this stand on a Blueberry site, are very frequent.

Pacific silver fir

Densely stocked stands dominated by Pacific silver fir that regenerated after windthrow are quite frequent (Figure 5.6.3). Pacific silver fir also grows in mixtures with Alaska yellow-cedar (Figure 5.6.4) or mountain hemlock (Figure 5.6.2). Nearly all the Pacific silver fir stands we observed had abundant advance regeneration, even under very low light conditions and without any ground surface disturbance. Younger advance regeneration or ingress performed best after release. Some older regeneration with sufficient foliage and a single leader (not bushy in form) also released successfully but was usually present in smaller numbers. The older the advance regeneration and the longer the period of suppression, the longer it appeared to take before growth accelerated, generally 2 to 10 years after release. This is possibly due to the increase in the ratio of respiration to photosynthetic rates of larger advance regeneration, saturation of photosynthetic capacity at lower rates of photosynthesis, and in some cases, photo-oxidation of several enzymes involved in photosynthesis, which reduces rates of photosynthesis when shade foliage is exposed to sunlight. When released, these larger residuals simply do not have the resources to rapidly convert shade leaves to sun leaves. Disturbed or friable forest floors are recommended planting substrates (Klinka *et al.* 1990b). The performance of seedlings planted in the mineral soil, where forest floors were thin, or where there was significant cover of *Vaccinium* spp., was inferior to that of naturally established seedlings.

Figure 5.6.3. A pure, densely stocked Pacific silver fir stand that likely regenerated after windthrow.
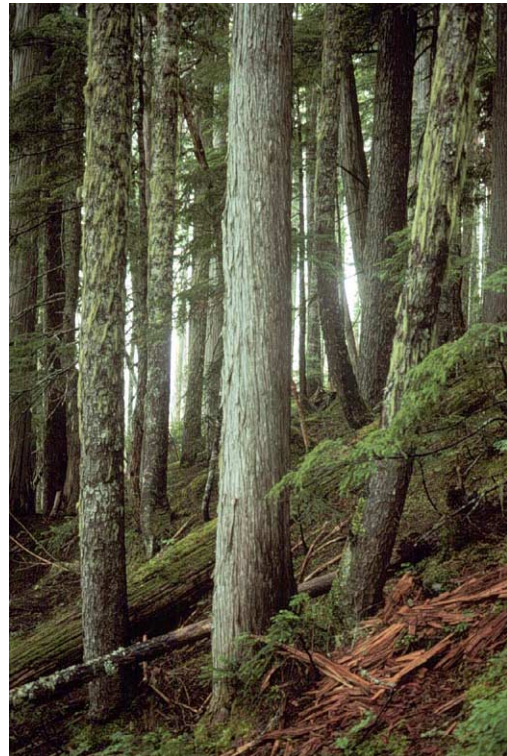
Figure 5.6.4. A closed-canopy stand dominated by Pacific silver fir and Alaska yellow-cedar.

Alaska yellow-cedar

Naturally regenerated Alaska yellow-cedar-dominated stands are infrequent, but not rare, and older than 300 years (Figure 5.6.5). They may have a closed or open canopy, and are either single- or multi-storied. Alaska yellow-cedar is commonly associated with mountain hemlock (Figure 5.6.6) or Pacific silver fir (Figure 5.6.4). In stands with at least some seed source, understory recruitment is often high; however, recruits rarely advance into the upper canopy layers when the light is less than approximately 10% of that above the canopy. The large amount of natural regeneration ingress on cutovers was surprising and appeared to occur regardless of the type of ground surface disturbance or size of the opening. Similar to mountain hemlock, Alaska yellow-cedar regeneration often features severe butt sweep, and often has forks and scars on the up-slope side, likely due to snowcreep. This damage can act as a source of entry for butt rot, a very common cause of decay in standing trees. Its greater occurrence on wind-exposed sites may be suggestive of greater windfirmness relative to Mountain hemlock and Pacific silver fir. Both mineral soil and well-decomposed forest floor materials are suitable planting substrates (Klinka *et al.* 1990b).

Figure 5.6.5. An old-growth stand dominated by Alaska yellow-cedar.

Figure 5.6.6. Alaska yellow-cedar growing in a mixed stand with mountain hemlock.

Subalpine fir

Similar to Pacific silver fir stands, nearly all subalpine fir stands that we observed had abundant advance regeneration under very low light conditions and without any ground surface disturbance. The vigour, growth form, and response to release in relation to age were also similar to that described for Pacific silver fir. Subalpine fir is often found on more continental sites on eastern Vancouver Island and on many submaritime sites (MHms variant) across the entire coastal region, particularly on parkland, water-deficient (often on limestone), insolated, skeletal, or cold sites (Figure 5.6.7). On these sites, the performance of subalpine fir was observed to be equal or superior to that of Pacific silver fir, both in plantations and in older forests (Figure 5.6.8).

Figure 5.6.7. Sublalpine fir on a limestone rock outcrop (left) and on a cold air drainage site (right) in the MHms variant.

Figure 5.6.8. Growth of subalpine fir is often comparable to that of Pacific silver fir, both in plantations and older stands.

Western white pine

Western white pine is a scattered species in both old-growth stands and second-growth stands in the coastal forest, except in the CDF zone. Its abundance increases with increasing elevation, until it reaches its peak distribution in the montane forest. However, it is found even in the MH parkland (Figure 5.6.9). Due to its productive growth (Figure 5.6.10), western white pine will occupy the upper tree layer, and thus contribute to the development of a marginally 2-storied stand structure. Western white pine was observed to consistently be one of the best performers (Figure 5.6.11), especially on warm-aspect, burned cutovers on the leeward side of Vancouver Island, but it was absent on the windward side and only scattered on the coastal mainland. It is possibly a useful indicator of a relatively recent fire history. A minor component of the species should be encouraged where it occurs naturally and it should be treated as a 'ghost tree' during spacing operations. Western white pine is an unsuitable species on very poor sites where it is affected by root dieback, but its wider use is mainly constrained by its susceptibility to blister rust infection. Therefore, if planted, it should be only one of the minor species on a site, unless blister rust-resistant or -tolerant planting stock can be obtained.

Figure 5.6.9. Western white pine is even found in the MH parkland.

Figure 5.6.10. The productivity of western white pine exceeds that of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar.
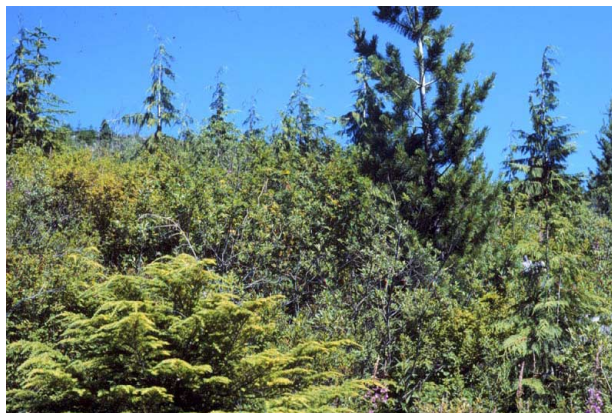
Figure 5.6.11. Western white pine regenerates naturally on disturbed sites and can quickly become a dominant species.

Engelmann spruce

Engelmann spruce, a continental subalpine boreal species, occurs as a scattered tree on the leeward side of the Coastal Mountains. Although it is most abundant in the ESSF zone, it grows most productively in the submaritime portion of the CWH zone. It is also found in the maritime-submaritime transition on warm-aspect sites (Figure 5.6.12). There are no reasons why Engelmann spruce could not be grown outside its native range on sites that are within its ecological (climatic and edaphic) amplitude, such as in the MHms variant and on some subalpine sites on the leeward side of Vancouver Island, which is somewhat less maritime than the typical climate of the MHmm variant. Indeed, a number of Engelmann spruce plantations in this area suggest that it is a viable species (Figure 5.6.13), and we agree with the evaluation of Scagel *et al.* (1989) who considered Engelmann spruce a good and reliable performer due to its consistent growth and good growth form. We observed height increments in excess of 50 cm, even at elevations of 1,400 to 1,500 m, and the seedlings matched or exceeded the perfomance of planted seedlings or advance regeneration of other species. Engelmann spruce appears to best suited for the relatively driest, warm-aspect, and leeward (less maritime) sites.

Figure 5.6.12. The westernmost population of Engelmann spruce grows on this colluvial site in the Chiliwack River valley.

Figure 5.6.13. Engelmann spruce seedlings planted five years ago on this high-elevation cutover have performed as well as the other naturally regenerated species.

Noble fir

Noble fir is a montane to subalpine, predominantly maritime, timber crop species, which occurs just south of 49° latitude (Figure 5.6.14). It is the most productive true fir species in the Pacific Northwest (Figure 5.6.15). There are no climatic reasons why noble fir could not be grown outside its native range on sites that are within its edaphic amplitude. Indeed, in operation trials at the lower elevation limit of the maritime portion of the MH zone, noble fir was occasionally observed to outperform Pacific silver fir on drier warm-aspect sites (Figure 5.6.16). On other sites, its performance was comparable, but not superior, to that of mountain hemlock and Alaska yellow-cedar. Noble fir appears to be quite resistant to snow damage, but less shade-tolerant, and possibly less frost-tolerant, than the indigenous mountain hemlock, Pacific silver fir and Alaska yellow-cedar.

Figure 5.6.14. Noble fir can be recognized by its blue-green foliage.

Figure 5.6.15. Noble fir exhibiting excellent form and a high productivity.

Figure 5.6.16. Naturally regenerated Douglas-fir and noble fir on a montane site. Both are the same height, but the noble fir has greater diameter growth.

Summary

Except on edaphically extreme sites, any combination of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar should be considered acceptable for regeneration of future forest stands, with preference given to mixed-species stands and, perhaps more representation of Alaska yellow-cedar, considering its value. Characterization of suitable seedbeds for natural regeneration and monitoring of regeneration performance are needed to ensure optimal regeneration decision-making and the best possible regeneration results.

Generally, relative to the other species the proportion of
- *Mountain hemlock increases with increasing elevation, and decreases with increasing N-availability and soil moisture.*
- *Pacific silver fir decreases with increasing elevation, and increases with increasing N-availability and soil moisture.*
- *Alaska yellow-cedar decreases with increasing continentality.*

Engelmann spruce, noble fir, subalpine fir and western white pine, whose centres of occurrence lie outside of the MH zone, may also be acceptable species on suitable microsites. With increasing continentality and on warm-aspect slopes, Engelmann spruce and subalpine fir may be considered suitable options. In the lower portion of the forested MH subzone, noble fir can be an option. Western white pine should be preserved where it naturally regererates, or considered as a minor species for planting where blister rust-resistant or -tolerant stock is available.

5.7 REPRODUCTION CUTTING OPTIONS

We predict escalating demands for the conservation of the coastal subalpine forest and for alternatives to the use of clearcutting. Large clearcuts are not acceptable for high retention, visual quality objectives, and may not be appropriate for maintenance of the hydrological and wildlife roles of the forest (Figure 5.7.1). The long regeneration period on steep-slope cutovers and the use of continuous clearcutting lead to problems in maintaining visual quality objectives. Selection cuttings and uneven-aged forest management are often seen as a better alternative to clearcutting and even-aged management (*e.g.*, Brooke *et al.* 1970; Vogt *et al.* 1989).

Figure 5.7.1. Progressive large-scale clearcutting is no longer acceptable in the coastal high-elevation forest.

There are no well-designed and implemented examples of different regeneration cutting methods in the MH zone. Our observations of the pattern and vigour of natural regeneration in relation to stand-edges, small canopy gaps, and aspect, gave many naturally occurring examples of the potential effectiveness of strip-shelterwoods, group-shelterwoods, uniform shelterwoods, or patch-cuttings. A 'partially cut' stand on the Sunshine Coast (Small Business Forest Enterprise Program) is an isolated example; it is probably best characterized as a release-cutting with the retention of scattered intermediate trees (future crop trees) and non-crop, old-growth residuals of Alaska yellow-cedar (Figures 5.7.2 and 5.7.3). The disturbance of the thick forest floor created a seedbed resulting in abundant ingress. Unfortunately the stand has a legacy of excessive landing areas, skidtrails, and fireguards. However, two years after cutting the stand features surviving advance regeneration of Pacific silver fir and abundant ingress of mountain hemlock and Alaska yellow-cedar. It is important that approved partial cuttings are well prescribed and executed, otherwise failures will lead to loss of public confidence through misrepresentation.

Figure 5.7.2. The parent true 'climax' stand on a Blueberry site in the MHmm variant prior to partial cutting.

Figure 5.7.3. Partial cutting preserved the advance regeneration and sub-canopy trees (top), as well as dead and living canopy trees (bottom).

Concepts, principles, and a framework for the selection of species- and site-specific cutting methods applicable for stands in the MH zone were outlined by Weetman *et al.* (1990), Klinka *et al.* (1990c) and Klinka and Carter (1991); however, the important economic repercussions of the decisions involved were not explicitly addressed. The following summary is based on these reports, and is also restricted to the physical and biological factors affecting the choice of regeneration cuttings in the MH zone.

Given the operational constraints in the MH zone, the poor availability of planting stock of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar, and the high potential for natural regeneration of these species, natural regeneration is the logical method for reforestation by these species (*e.g.*, Scagel *et al.* 1989; Vogt *et al.* 1989). This will require (i) the preservation of acceptable advance regeneration, (ii) the creation of seedbed conditions favourable for ingress of natural regeneration of desired species, and (iii) the rare use of fire, such as on naturally degraded sites (see Section 4.1 STAND STRUCTURE AND FOREST DYNAMICS on page 99).

The choice of the reproduction cutting method will depend on the presense or potential for regeneration. Three regeneration scenarios can be encountered:

1. adequate advance regeneration is present in the moss and herb or shrub layers (Figure 5.7.4);
2. inadequate advance regeneration but natural regeneration is a viable option (Figure 5.7.5); or
3. neither situation is present.

If, in this scenario, planting is not feasible, then cutting should be deferred.

Figure 5.7.4. Prolific young advance regeneration in the herb layer usually results in good regeneration (left), while taller advance regeneration in the shrub layer (right) with a history of suppression may or may not result in successful natural regeneration.
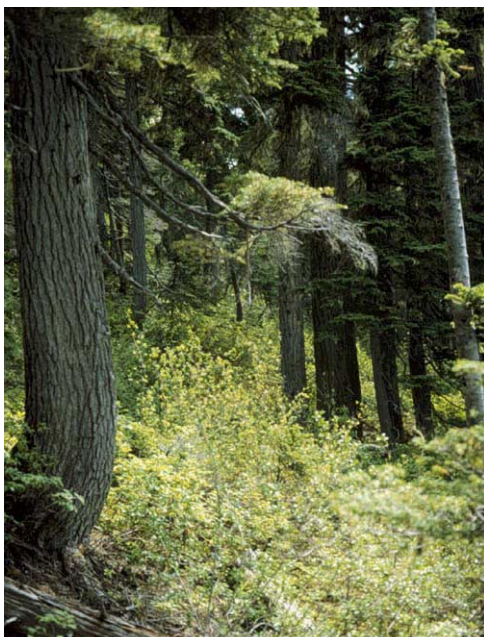
Figure 5.7.5. Stands without advance regeneration. This scenario may result in natural regeneration through ingress providing that the appropriate reproduction method is selected.

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For any of these scenarios, it must be determined whether the species to be regenerated on a site will require protection or if it will tolerate exposure. Regeneration of mountain hemlock, Pacific silver fir and Alaska yellow-cedar will require temporary or prolonged protection by the parent tree canopy on:

1. high snowpack sites (>2.5 m of snow accumulation, typically at the upper elevation limit of the forested MH subzones) (see Figure 4.2.7);
2. snowcreep sites (Figure 5.7.6);
3. sites prone to growing-season frost (frost pockets and cool air drainage sites, which may have a small or large area depending on the physiography of the landscape, (see Section 3.2 ZONAL CLASSIFICATION - Zonation and Climatic Localisms on page 26) (Figure 5.7.7); and
4. wind-exposed sites.
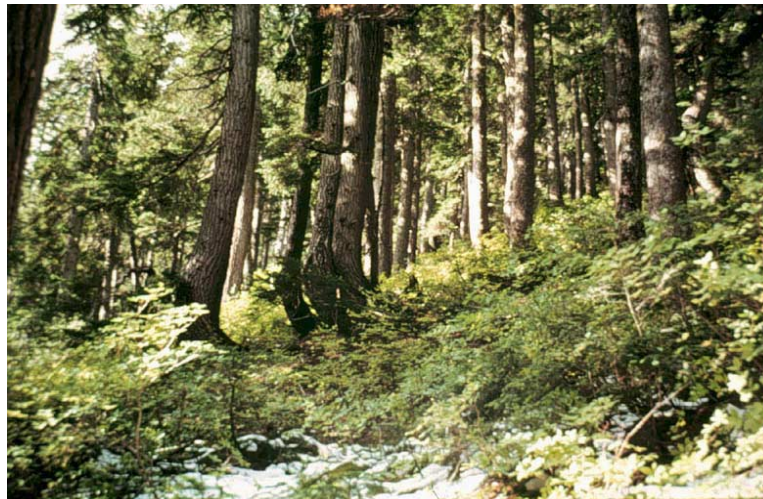
Figure 5.7.6. Snowcreep sites can be recognized by butt sweeps.

Figure 5.7.7. Advance regeneration is absent or it grows poorly in frost pockets or cool air drainages.

Mountain Hemlock Zone

Protection from frost, wind, and a deep and prolonged snowpack can be achieved with the use of shelterwood cuttings (providing temporary protection) or selection cuttings (providing prolonged protection). The level of canopy retention in shelterwood and selection systems should:

1. allow for reasonable growth of advance natural regeneration, (*e.g.*, for Pacific silver fir an understory light level >35% of above canopy light is necessary for leader growth to exceed lateral growth (Klinka *et al.* 1992)), while still providing adequate overstory protection;
2. check the development of understory vegetation so that it will neither impede natural seeding or reduce light below the level necessary for survival and growth of seedlings; and
3. maintain the integrity of the residual stand in terms of its structure, density (minimum basal area) and wind-firmness.

On sites not affected by high snowpack, growing season frost or strong wind, Mountain hemlock, Pacific silver fir and Alaska yellow-cedar are considered to be exposure-tolerant species, which means they can (but do not need to be) regenerate without protection of the parent tree canopy.

The age, form, vigour, composition and spatial pattern of the regeneration may vary within each stand and between stands of the same developmental stage. If adequate advance regeneration is present in the forest understory (regeneration scenario 1), then the overstory can be removed either (i) completely and at a single point in time by clear-felling, (ii) completely over an extended period of time by shelterwood cuts (if prolonged site occupancy by trees is desired) or (iii) gradually over an indefinite period of time by selection cuts (if continuous site occupancy with trees is desired). All three cutting methods can be applied in the absence of advance regeneration providing that the existing or potential competing vegetation will neither impede natural seeding or reduce light below the level necessary for survival and growth of seedlings on a site [scenario 2]. However, the dispersal distance of Pacific silver fir seed is limited and should not be expected to extend much beyond 40 m from the source trees (Franklin 1966; Carkin *et al.* 1978). In addition, all of these harvesting options require infrastructure development, which will need to be accessible over several years to decades. These associated costs and the ecological considerations must be factored in to any operational plan.

It may seem that the most suitable candidates for selection cuttings are true old-growth stands. However, such stands were almost exclusively characterized as nutritionally deficient ecosystems, in which mobilization of the nutrient capital in the forest floor will be desirable if they are to be revitalized. Selection cuttings may not provide environmental conditions for such revitalization.

Sites without advance regeneration or a potential for natural regeneration (scenario 3) will require planting. To facilitate planting, clear-felling (strip-shelterwood, patch-cuts, or clearcuts) is the most feasible means for preparing such sites. Any regeneration cutting method should be selected after considering of its effect on snowpack and snowmelt. We observed that seedlings were flushing as late as the end of July on high snowpack cutovers. Flushing on sites with protective tree canopies occurred much earlier as snowmelt was generally 2-4 weeks earlier than on clearcuts. This may represent an important increase in the length of the growing season, and therefore growth.

Summary

Given the physical and operational constraints and the high potential for natural regeneration in the subalpine MH forest, it could be more feasible to modify the size, shape, layout, and design of clearcuts rather than to embark on the wide use of uniform shelterwood and selection cuttings. This will require allocation of appropriate cutting methods to particular stands at a particular time, which necessitates more roads and improved road access over many years in difficult road building conditions with risks of road failures. The development of a desirable cutting pattern in the forest through time and space would help in conserving the forest and its values. Some examples of shelterwood and selection cuttings, however, are needed so that their role can be properly assessed.

5.8 REGENERATION ON DISTURBED SITES

In spite of previous concerns and recommendations and a lack of precedents for regenerating the coastal subalpine forest, there has been no systematic effort to collect species- and site-specific data for characterization of (i) the pre- and post-cutting structure, growth, and dynamics of advance regeneration and (ii) the rate, patterns, growth and dynamics of ingress of post-cutting natural regeneration on cutovers with various histories of disturbance. As a result, no predictions of the time frame needed for regeneration establishment and growth can be made. It appears that while the free-to-grow stage can be reached in as little as 10 years in ideal situations, in many other situations a period of over 20 years will likely be required.

We are convinced that natural regeneration on the majority of cutovers is either free-growing already or will be free-growing, although often not in accordance with the desired tree species, time period, and uniformity criteria set in current stocking standards (BC Ministry of Forests 1990). The principal exception to this confidence that free-growing status has or will be achieved in a 'timely' manner is the legacy of cutovers that were slashburned, primarily before 1980. Many of these cutovers remain non-satisfactorily restocked, and while natural regeneration has established on some, it has not, and likely will not, establish on some others. We are uncertain whether planting beyond the extent required to achieve reforestation could be advantageous and preferable to natural regeneration. Thus, with the aid of planting on some sites, we consider regeneration of cutovers in the MH zone more successful and less problematic than in the subalpine Engelmann Spruce - Subalpine Fir zone (*e.g.,* Butt 1990).

The cutovers we observed originated as long as 30 years ago. Assuming that mountain hemlock, Pacific silver fir, and Alaska yellow-cedar are all acceptable species, and considering stocking standards (Silviculture Branch 1990), the regeneration status of cutovers in the MH zone was observed as follows:

1. regeneration on nearly all old, unburned cutovers was free-to-grow and satisfactorily stocked (often over-stocked), but often failed to meet the criteria of desirable distribution or spacing (*i.e.,* regeneration occurred in irregularly distributed, overcrowded patches/clumps);
2. on many recent unburned cutovers where the regeneration has not yet reached the free-to-grow stage it will likely do so in the near future through ingress. However, it is predicted to (i) often exceed the upper time limit set for the free-growing assessment period and (ii) fail to meet the spacing criteria as described above;
3. a few old and recent cutovers showed little or no natural regeneration. Unless planted, they will require an unknown period of time (greatly exceeding the time limit allowed under current stocking guidelines) for natural regeneration. Control of competing vegetation (typically ericaceous shrub thickets, and, less frequently, herbaceous vegetation) will often be required before successful planting can take place;
4. survival and growth of planted Pacific silver fir seedlings was observed to be inferior to Alaska yellow-cedar seedlings.

The early successional sequence of natural regeneration on unburned cutovers for the stand initiation and the stem exclusion stage is generalized in the following sequence of visuals:

1. in the early stand initiation stage the advance regeneration, when present, responds to release and ingress establishes. Generally, the regeneration is distributed randomly in clumps, which are interspersed with gaps (Figure 5.8.1);
2. in the late stand initiation stage the gaps decrease in size due to the expansion of the groups (Figure 5.8.2);
3. by the early stem exlusion stage, the gaps become quite small (Figure 5.8.3);
4. later in the stem exlusion phase the canopy closes and very little light reaches the understory (Figure 5.8.4).

Figure 5.8.1. A dense cohort of naturally established Pacific silver fir in the early initiation stage of stand development.

Figure 5.8.2. A dense stand of naturally regenerated Pacific silver fir in the late initiation stage of stand development.

Figure 5.8.3. A dense cohort of naturally regenerated Pacific silver fir in the early stem exclusion stage of stand development.

Figure 5.8.4. A dense stand of Pacific silver fir in the late stem exlusion stage of stand development.

The cutovers we observed were diverse in the patterns of vegetation, abundance and growth of advance regeneration, ingress, and planted seedlings. The diversity is a result of the differing ecological and silvical attributes of the three major tree species, the varied ecological site quality, structural characteristics and understory vegetation of the original stands, and the different types of disturbance. Some of these regeneration patterns in relation to site and disturbance features are outlined below.

Composition and distribution of advance regeneration

Advance regeneration of mountain hemlock and Alaska yellow-cedar in the understory of closed-canopy stands in the MH zone was much less frequent than that of Pacific silver fir and occurred predominantly in gaps in old-growth stands. In the open, advance regeneration survived exclusively on unburned cutovers, and was consistently dominated by Pacific silver fir. The advance regeneration can be protected by the slash when small (Figure 5.8.5) or a deliberate attempt can be made to preserve taller regeneration (Figure 5.8.6). Accounting for mortality caused by cutting and yarding operations and exposure, the distribution and structure of Pacific silver fir regeneration basically corresponded to that found in adjacent old-growth stands - typically patchy with overcrowded clumps. Narrow clearcuts (simulating strip-shelterwoods) and stand-edges appeared to have more abundant and vigorous advance regeneration and ingress than large clearcuts (Wagner 1980). This was likely due to the interaction between seed source and protection from abiotic elements.

Figure 5.8.5. On this clearcut only very young advance regeneration, which is partly protected by slash, was preserved.

Figure 5.8.6. On this clearcut a deliberate attempt was made to preserve also taller advance regeneration.

Release of regeneration

Ericaceous shrubs (mainly *Vaccinium* spp.) were most vigorous on slashburned cutovers, but were also present on unburned and otherwise relatively undisturbed sites that originally supported climax stands (for definition of climax, see Section 4.1 STAND STRUCTURE AND FOREST DYNAMICS on page 99). Since seedlings in the open are limited by snowpack (Figure 5.8.7), some degree of shelter by the overstory or lesser vegetation, such as ericaceous shrubs, appears to aid regeneration establishment. However, the excessive cover of ericaceous shrubs can reduce seedling establishment and growth in older cutovers (Figure 5.8.8). Advance regeneration overtopped by canopies of ericaceous shrubs at the time of overstory release appeared to have the potential to eventually outgrow the shrub layer. The time needed is unknown, and will depend on the response of shrubs to exposure. Mountain hemlock, Pacific silver fir and Alaska yellow-cedar all can respond well to release even after long periods of suppression (Herring and Etheridge 1976; Klinka *et al.* 1992). Younger seedlings (Figure 5.8.9) generally respond better to release than older suppressed advance regeneration (Figure 5.8.10).

Figure 5.8.7. Abundant natural regeneration of Pacific silver fir and mountain hemlock in the open on undisturbed forest floor.

Figure 5.8.8. The growth of these seedlings under a dense canopy of blueberries is limited by low light.

Figure 5.8.9. Younger regeneration, such as these mountain hemlock seedlings, generally respond well to release.

Figure 5.8.10. This Alaska yellow-cedar sapling, which regenerated in a canopy gap is estimated to be >75 years old, and will likely respond poorly to release.

Composition and distribution of ingress

Post-cutting ingress was variable in terms of rate, survival, species composition (generally Alaska yellow-cedar > mountain hemlock > Pacific silver fir), and distribution (uneven and patchy), but appeared to be steady, and often surprisingly abundant. The size of the opening did not appear to be the dominant factor controlling rates of ingress for mountain hemlock or Alaska yellow-cedar, but rates of ingress of Pacific silver fir did appear to be strongly influenced by the species composition of adjacent mature stands, cutover size, and orientation to the prevailing wind.

We surmise that the establishment and growth of ingress is related to microsite characteristics. These include: substrate (*e.g.*, decaying wood, undisturbed forest floor or disturbed forest floor), microclimate (*i.e.*, exposure; warm- *versus* cool-aspect), depth and duration of snowpack (upslope *versus* downslope microsites in relation to stumps/mounds and depressions), and the vegetation present on a microsite (protected *versus* unprotected/exposed microsites). As the effects of microsite are further complicated and obscured by temporary changes in the vegetation remaining on a site, it is difficult to understand the patterns and to construe possible

relationships. For example, under comparable circumstances, in some situations we found abundant, relatively young surviving seedlings underneath dense ericaceous shrub thickets, while in other situations ingress occurred close to, but outside of, ericaceous cover, typically on the shelter-providing aspect of mounds surrounding stumps.

Regeneration and forest floor relationships

Sites that either originally had friable forest floors (Mormoder or Moder humus forms) (Figure 5.8.11), water-receiving sites, sites that originally supported dense-canopy stands with little or no advance regeneration and Mor humus forms, which upon exposure have developed into friable forest floors (Figure 5.8.12), did not povide a suitable seedbed for ingress. After cutting, dense early seral herb (*e.g.*, Epilobium angustifolium or Veratrum viride) and/or non-ericaceous shrub communities (*e.g.*, Oplopanax horridus or Rubus spectabilis) develop on these sites, effectively preventing both ingress of natural regeneration and planting. In these stands we observed advance regeneration to be restricted to decaying wood microsites or lacking. Sites that developed friable forest floors after cutting manifested an 'assart effect' (a rapid release of plant-available nutrients formerly stored in biomass), and were usually located on warm-aspect slopes and base-rich soils. Green and Bernardy (1991) studied these two scenarios in the Chipmunk Creek area.

Figure 5.8.11. On this nutrient-rich cutover a dense shrub and fern community hinders ingress and planting.

Figure 5.8.12. This site developed a friable forest floor (Moder humus form) after cutting, which rendered an unsuitable seedbed for ingress of Pacific silver fir.

Advance regeneration on sites that originally supported climax stands was generally chlorotic and in check, presumably due to nitrogen (and possibly phosphorus) deficiency. This occurred where there was abundant ericaceous cover (*Vaccinium* spp.) and on undisturbed, compacted, thick forest floors dominated by roots and decaying wood. In one research trial, removal of ericaceous species resulted in a remarkable improvement in foliage colour and growth; however, such cleaning operations are hardly economically justifiable in the MH zone. Some disturbance of these deep, lignic forest floors during cutting would likely be desirable, as it would stimulate decomposition on these generally very poor sites.

The response of established advance regeneration of Pacific silver fir to release varied with snowpack and substrate. As expected, the response decreased with increasing snowpack. When the substrate was a deep layer of decaying wood (Lignomor and Resimor humus forms) subject to acute water deficit, the response generally was poor (low vigour and chlorotic foliage) (Figure 5.8.13). When the substrate undergoes an assart effect as manifested by the presence of fireweed and there was no water deficit, the response of established Pacific silver fir advance regeneration was excellent (Figure 5.8.14).
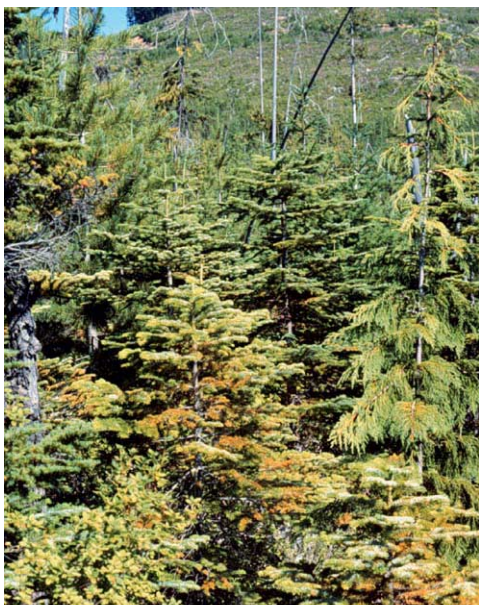
Mountain Hemlock Zone

Figure 5.8.13. The response of Pacific silver fir advance regeneration growing on a deep layer of decaying wood subject to water deficit is poor. Note the low vigour and chlorotic foliage.

Figure 5.8.14. If the substrate undergoes an assart effect, as manifested by the presence of fireweed, Pacific silver fir advance regeneration will respond well to release.

Slashburning

Slashburned cutovers have the potential to be regenerated naturally but they will require more time, with increasing regeneration delay with increasing impact of the fire (Figures 5.8.15 and 5.8.16). This delay could be from 50 to over 100 years on steep, severely burned warm-aspect sites (Figure 5.8.17). Ingress of mountain hemlock and Alaska yellow-cedar, and occasionally western white pine, is generally slow and patchy, and may be prevented almost completely by earlier establishment and growth of ericaceous shrubs (Figure 5.8.18). Slashburning has been regarded as a detrimental practice in the MH zone considering its adverse impact on regeneration (*e.g.*, Klinka 1977; Feller 1982; Vogt *et al.* 1989).

Figure 5.8.15. The high severity of the burn in this area is indicated by the exposed lateral roots of this Pacific silver fir stump.

Figure 5.8.16. An unusual *Calamagrostis canadensis* community developed in this severely burnt high-elevation cutover.

Figure 5.8.17. Very slow, scattered ingress of predominantly mountain hemlock and Alaska yellow-cedar on a burned high-elevation cutover.

Figure 5.8.18. Broadcast burning of this high-elevation cutover destroyed the natural advance regeneration and resulted in the development of a *Vaccinium*-dominated shrub community.

Concluding remarks

Vogt *et al.* (1989) stated that natural regeneration is ubiquitous in the MH zone. While this is not true, the potential for natural regeneration is predictable. The ecological circumstances of poor regeneration, both of advance regeneration in the forest understory and on cutovers and of ingress on cutovers, appear to be very similar. Successful management of stands prone to poor natural regeneration will require their identification during pre-harvest silvicultural prescriptions.

Summary

A large number of cutovers in the coastal subalpine forest were occupied by a satisfactory amount of advance regeneration and/or showed ingress of post-cutting regeneration. Relatively few cutovers were considered non-satisfactorily restocked and without potential for natural regeneration. Advance regeneration responded well to release, and ingress appeared to be steady, accumulating over time, and, for mountain hemlock and Alaska yellow-cedar, does not appear to be very dependent on cutover size but on microsite quality. A legacy of slashburning has imparted a strongly detrimental impact on regeneration and future productivity to some cutovers. Although the potential for natural regeneration is predictable, knowledge of suitable microsites and the dynamics of ingress and lesser vegetation is sparse.

5.9 NATURAL REGENERATION AFTER CLEARCUTTING: A CASE STUDY

The most feasible option for reforesting cutovers in the MH zone is natural regeneration with Pacific silver fir, mountain hemlock and Alaska yellow-cedar mixtures, but there are uncertainties about the temporal and spatial patterns of regeneration. Regeneration patterns were investigated on 6 sites that were clearcut about 10 years prior to sampling and left to regenerate naturally.

Temporal pattern:
Most trees taller than 100 cm established before cutting (Figure 5.9.1). Trees that established ≥2 years before cutting (residuals) accounted for 35% of all trees and their mean height at the time of cutting was 50 cm. Trees that established in the 3-year window from the year before cutting to the year after cutting (germinants) formed a surprisingly high proportion (45%) of regeneration. Most residuals were Pacific silver fir while almost half of germinants were Alaska yellow-cedar (Figure 5.9.1). There was little ingress 2 years after cutting, and none after 8 years. This illustrates the importance of trees that had already established (*i.e.*, advance regeneration), in the previous stand, especially when clearcutting removed all nearby seed-producing trees.
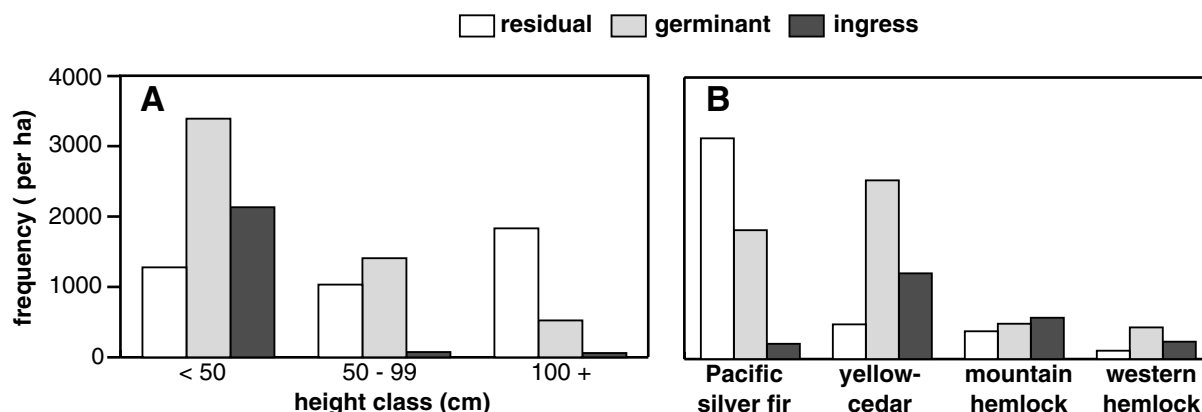
Figure 5.9.1. Age class distribution by (A) height class and (B) species recorded 10 years after logging.

Spatial pattern:
Cutting resulted in increased cover of disturbed forest floor substrates (Figure 5.9.2). In spite of covering <50% of the ground surface, undisturbed forest floor supported approximately 90% of regeneration, regardless of age or height. Regeneration was less common on mounds than in adjacent old-growth stands, probably because mounds were the microsites most likely to be disturbed during cutting.
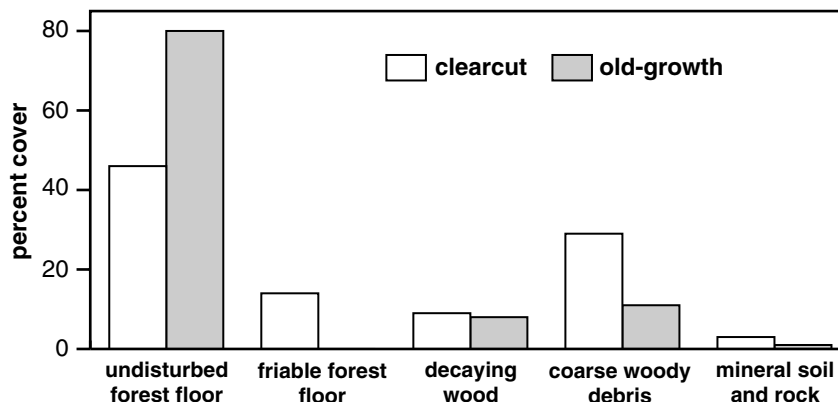
Figure 5.9.2. Cover of ground surface substrates on clearcuts and adjacent old-growth stands.

The dense cover of blueberry shrubs on many cutovers in the MH zone can give the impression that these shrubs impede tree establishment and survival. On the 6 study sites, however, 84% of regeneration was growing with blueberry (Figure 5.9.3) and there was no indication that blueberry decreased survival or height growth. This neutral or positive effect of blueberry was due to at least two factors. First, blueberry was more common on undisturbed substrates, which in turn, were related to more abundant regeneration; and second, blueberry may have helped protect regeneration from snow damage.
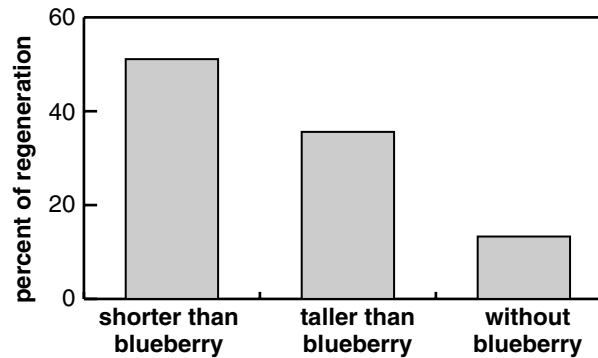
Figure 5.9.3. Percentage of trees growing with blueberry shrubs.

With some exception, clearcuts in the lower elevation limit of the MHmm subzone will be regenerated naturally, though often accompanied by a shift to Pacific silver fir and a clumped spatial pattern. New stands will also have lower structural diversity since they will be essentially single-storied. Deeper snow increases the proportion of regeneration that requires the protection of an overhead canopy - a property most commonly associated with high-elevation tree islands. This tendency is most evident where snow melts latest, for example, on cool-aspect and flat sites. Regeneration is usually absent in large canopy gaps where snow remains into June. Therefore, we can expect that deeper snow at higher elevations will cause regeneration problems without the protection of an overhead canopy. Given these climatic conditions, any form of clear-felling (clearcutting, patch-cutting, seed-tree cutting, or strip- or group shelterwood cutting) is biologically inappropriate since it creates adverse conditions for the establishment, survival and growth of trees. In stands where natural regeneration is feasible, a simple form of selection cutting could be used that maintains some of the overhead canopy by retaining some live and dead canopy tree and most sub-canopy trees.

5.10 SUMMARY OF MANAGEMENT ISSUES AND RESEARCH NEEDS

A large area of the old-growth stands of the coastal subalpine forest has been, or is intended to be, cut without an explicit commitment to the certain and continuous production of timber crops and other goods or services. Low-elevation cutting and road construction practices have been extended to this forest without a clear understanding of forest dynamics and without sufficient concern about the impact of cutting on future timber, hydrological, wildlife, scenic and recreation values. Can the present mode of cutting be justified? Is it possible to manage the forest on a sustained yield basis, given the slow growth rates of trees? Do the present management practices represent the best available option? What is the best possible type of management? It is very difficult to answer these questions from a scientific perspective.

To help resolve these issues and problems, we offer the following ways to answer these questions:

1. improve the inventory data base; in particular, monitor the growth performance of regeneration;
2. increase the intensity of research;
3. update the field guides for site identification and interpretation and other guidelines (standards);
4. develop special policy, goals, and management strategies jointly between industry, government, and the public;
5. acquaint the public with the special characteristics of the MH zone, and with the management options;
6. enforce visual quality objectives.

Management of the coastal subalpine forest requires the support of both basic and applied research. We recommend that the studies proposed below be considered, supported and implemented. The list that follows does not pretend to be a master research plan; instead it represents an integrated program which aims to identify gaps in our knowledge of the factors controlling the establishment and growth of the trees, and the role of the forest.

1. Studies of ecosystems missed in the Ecological Classification Program.
2. Site- and microsite-specific exploratory and experimental studies of the ecological and silvical characteristics of mountain hemlock, Pacific silver fir, and Alaska yellow-cedar, focusing on seed production, seed dispersal, shade tolerance, and phenological characteristics.
3. Site- and microsite-specific exploratory studies of the response (growth performance) of advance regeneration of mountain hemlock, Pacific silver fir and Alaska yellow-cedar on cutovers in relation to their age, vigour and crowding.
4. Site-specific experimental studies of the effects of (i) climate (snowpack, length of the growing season, soil and air temperature, and the incidence and timing of frost), (ii) substrate, (iii) microclimate (in relation to microsite), and (iv) lesser vegetation on the germination, survival, and growth performance of planted or naturally regenerated mountain hemlock, Pacific silver fir, and Alaska yellow-cedar.
5. Site-specific exploratory studies of the recruitment (in terms of germination, survival and growth rate) of mountain hemlock, Pacific silver fir and Alaska yellow-cedar natural regeneration immediately following clearcutting until crown closure in relation to snowpack, substrate, microclimate and lesser vegetation.
6. Site-specific exploratory studies of the origin, structure and future development of old-growth stands focussing on the growth-form of trees, their causes of mortality and the pattern and dynamics of natural regeneration (germination, survival and growth rate) in relation to snowpack, substrates, microsites and lesser vegetation.

Studies 1 through 6 would provide the database for making site-specific predictions about (i) natural regeneration (density, stocking uniformity and growth rate), (ii) suitable microsites for seedling establishment, (iii) potential stocking, and (iv) acceptable advance regeneration, and they would provide an opportunity for reassessment of the current stocking guidelines.

7. Studies investigating how to increase the current production levels of Alaska yellow-cedar seed and seedlings.

8. Site-specific studies of single- and mixed-species stands producing information on (i) forest productivity, (ii) net primary productivity and (iii) relationships between ecological measures of site quality and forest productivity.

9. Studies elucidating the hydrological and wildlife role of the forest at the watershed/landscape level (undisturbed *versus* partially denuded *versus* denuded areas).

10. Classification (management zoning) of the forest according to (i) its value as a timber source according to 'present value', (ii) its suitability for timber production, and (iii) conservation criteria (identified non-timber values). This would involve re-examination of the criteria used to delineate environmentally sensitive areas.

11. Economic and strategic analyses of the timber supply considering management zoning and examining (i) the impact of a reduced AAC (annual allowable cut) in the MH zone in relation to accelerated operability (through incremental silviculture in low-elevation, second-growth stands), (ii) the impact of smaller and scattered cuttings in the MH zone, or dividing TSAs (timber supply areas) into smaller working circles on the present AAC level, and (iii) sensitivity of the present AAC level to changes in old-growth-growth yield curves, the use of harvesting methods other than clearcutting, regeneration delays and assumptions about the yield of second-growth.

12. Development of a silvicultural guide for MH zone working groups (similar to those produced by the Ontario Ministry of Natural Resources, e.g. Arnup *et al.* (1988)).

6 REFERENCES

Agriculture Canada Expert Committee on Soil Survey. 1987. The Canadian system of soil classification. 2nd Ed. Agric. Can. Publ. 1646. Ottawa, Ont.

Archer, A.C. 1963. Some synecological problems in the alpine zone of Garibaldi Park. M.Sc. Thesis, Univ. of British Columbia, Vancouver, BC.

Arno, S.F. 1966. Interpreting the timberline: an aid to help park naturalists to acquaint visitors with the sub-alpine-alpine ecotone of western North America. M.F. Thesis, Univ. Montana, Missoula, Montana.

Arnott, J.T. 1991. Englemann spruce trial on Mount Washington, Vancouver Island - 7 year results. File Rep. PC-61-02, Pacific Forestry Centre, Forestry Canada, Victoria, BC. 16 pp.

Arnott, J.T. and F.T. Pendl. 1991. High elevation species and stock type trials. Notes for the Mount Cain field tour, July 18, 1991. File Rep. PC-61-02, Pacific Forestry Centre, Forestry Canada, Victoria, BC. 12 pp.

Arnott, J.T., D. Beddows, and F.T. Pendl. 1989. High elevation species and stock type trials. A report prepared for the Forest Establishment Research Group field tour, June 28, 1989, File Rep. PC-61-02. Pacific Forestry Centre, Forestry Canada, Victoria, BC. 26 pp.

Arnup, R.W., B.A. Campbell, R.P. Raber, M.F. Squires, K.D. Virgo, V.H. Wearn and R.G. White. 1988. A silvi-cultural guide for the spruce working group in Ontario. Ontario Min. of Nat. Resources Group, Science and Tech. Series Vol. 4. Ont. Min. Nat. Res. 100 pp.

Banner, B., W. MacKenzie, S. Haeussler, S. Thomson, J. Pojar, and R. Trowbridge. 1993. A field guide to site identification and interpretation for the Prince Rupert Forest Region. BC. Min. For. Res. Prog., Land Manage. Handbook No. 26.

B.A. Blackwell and Associates Ltd. 2000. Terrestrial ecosystem mapping of Canadian Forest Products Ltd. Tree Farm License 37. Contract report for Canadian Forest Products Ltd.

Barkman, J.J., J. Moravec, and S. Rauschert. 1976. Code of phytosociological nomenclature. Vegetatio 32:131-185.

Association of BC Professional Foresters. 1996. The ABCPF Code of Ethics.

BC Ministry of the Environment. 1985. Summary of snow survey measurements in British Columbia 1935-1985. BC. Min. Env., Water Manage. Branch, Victoria, BC.

BC Ministry of Forests. 1993. Guidelines for tree species selection and stocking standards for British Colum-bia. Govt. of Canada - BC Partnership Agreement on Forest Resource Development. FRDA II. ISBN 0-7726-1910-7. 328 pp.

Becking, R.W. 1957. The Zürich-Montpellier School of phytosociology. Bot. Rev. 23: 411-488.

Beese, W.J. 1981. Vegetation-environment relationships of forest communities in central eastern Vancouver Island. M.F. Thesis, Univ. of British Columbia, Vancouver, BC.

Braun-Blanquet, J. 1951. Pflanzensoziologie. Grundzüge der Vegetationskunde. 2 Aufl., Springer-Verlag, Wien. [*in German*]

Brett, R.B. 1997a. Regeneration patterns on some old-growth and clearcut sites in the Mountain Hemlock Zone of southern British Columbia. M.Sc.Thesis, Univ. of British Columbia, Vancouver, BC.

Brett, R.B. 1997b. Regeneration patterns in the Mountain Hemlock zone. Scientia Silvica Extension Series Number 6, For. Sci. Dept, Univ. of British Columbia, Vancouver, BC. ISSN 1209-952X.

Brett, R.B. 1997c. Natural regeneration on clearcuts at the lower limit of the mountain hemlock zone. Scientia Silvica Extension Series Number 7, For. Sci. Dept, Univ. of British Columbia, Vancouver, BC. ISSN 1209-952X.

Brett, R.B., K. Klinka and H. Quian. 1998. Classification of high-elevation non-forested plant communities in coastal British Columbia. Scientia Silvica Extention Series, Forest Sciences Department, University of British Columbia, Vancouver, BC. ISSN1209-952X.

Briffa, K.R., P.D. Jones, and F. H. Schweingruber. 1988. Summer temperature patterns over Europe: a reconstruction from 1750 A.D. based on maximum latewood density indices of conifers. Quaternary Res. 30: 36-52.

Brink, V.C. 1959. A directional change in the subalpine forest-heath ecotone in Garibaldi Park, British Columbia. Ecology 40: 10-16.

Brooke, R.C., E.B. Peterson, and V.J. Krajina. 1970. The subalpine Mountain Hemlock zone. Ecol. Western N. Amer. 2: 148-349.

Burns, R.M. and B.H. Honkala. 1990. Silvics of North America. Vol. 1 Conifers. USDA For. Serv. Agri. Handbook 445, Washington, D.C. 675 pp.

Butt, G. 1990. Forest regeneration in the ESSF subzone: a problem analysis. FRDA Rep. 118, BC. Min. For., Victoria BC. 47 pp.

Carkin, R.E., J.F. Franklin, J. Booth, and C.E. Smith. 1978. Seeding habits of upper-slope trees. IV. Seed flight of noble fir and Pacific silver fir. Res. Note PNW-312, USDA For. Serv., Pacific Northwest For. and Range Exp. Stn. Portland, Oregon.

Carmean, W.H. and D.J. Lenthall. 1989. Height growth and site index curves for jack pine in north central Ontario. Can. J. For. Res. 19: 215-224.

Chen, H.Y.H., K. Klinka, and R.D. Kabzems. 1998. Site index, site quality, and foliar nutrients of trembling aspen: relationships and predictions. Can. J. For. Res. 28:1743-1755.

Christy, E.J., and R.N. Mack. 1984. Variation of juvenile *Tsuga heterophylla* across the substratum mosaic. J. Ecol. 72:75-91.

Cline, M.G. 1949. Basic principles of soil classification. Soil Sci. 67:17-22.

Dahl, E. 1956. Rondane. Mountain vegetation in South Norway and its relation to the environment. Norske Vidensk.-Akad. Oslo, Mat-Naturv. Kl., Skr. 1956(3): 1-374.

Dobry, J. and K. Klinka. 1998. Reconstructing temperature from tree rings of Pacific silver fir in coastal British Columbia. Northwest Science 72: 81-87.

Douglas, G.W. 1970. A vegetation study in the subalpine zone of the western North Cascades, Washington. M.S. thesis, Univ. Washington, Seattle, Washington.

Ellenberg, H. 1988. Vegetation ecology of central Europe. 4th ed. Cambridge University Press, Cambridge, UK.

Emanuel, J. 1999. VTAB Ecosystem Reporter Revision 199907a. Department of Forest Sciences, Univ. of British Columbia, Vancouver, BC.

Ettl, G.J. and D.L. Peterson. 1995. Growth response of subalpine fir (*Abies lasiocarpa*) to climate in the Olympic Mountains. Global Change in Biology 1: 213-230.

Evans, R.D. 1986. The relationships between snowmelt and subalpine meadow community pattern, Excelsior Ridge, western North Cascades. M.S. Thesis, Western Washington Univ., Bellingham, Washington.

Feller, M.C. 1982. The ecological effects of slashburning with particular reference to British Columbia: a literature review. Land Manage. Rep. 13, BC. Min. For., Victoria, BC. 60 pp.

Franklin, J.F. 1962. Mountain hemlock, a bibliography with abstracts. Res. Paper 51, USDA For. Serv., Pacific For. and Range Exp. Stn., Portland, Oregon. 216 pp.

Franklin, J.F. 1966. Vegetation and soils in the subalpine forests of the southern Washington Cascade Range. Ph.D. Thesis, Washington State University, Pullman, Washington. 132 pp.

Franklin, J.F. and C.T. Dyrness. 1988. Natural vegetation of Oregon and Washington. Oregon State Univ. Press, Corvallis, Oregon. 452 pp.

Franklin, J.F., W.H. Moir, G.W. Douglas, and C. Wiberg. 1971. Invasion of subalpine meadows by trees in the Cascade Range, Washington and Oregon. Arctic and Alpine Res. 3(3): 215-224.

Fritts, H.C. 1970. Tree-ring analysis and reconstruction of past environments. Vancouver, University of British Columbia Faculty of Forestry, Bull. No. 7: 92-98.

Garfinkel, H.L., and L.B. Brubaker. 1980. Modern climate-tree-growth relationships and climatic reconstruction in sub-Arctic Alaska. Nature 286:72-874.

Gilmour, J.R. 1973. Interim guidelines for the Vancouver Forest District: logging on severe sites. Unpublished Rep., BC. For. Serv., Victoria, BC. 7 pp.

Graham, R.L., P. Farnum, R. Timmins, and G.A. Ritchie. 1984. Using modelling as a tool to increase forest productivity and value. Pp. 101-130 in Weyerhauser Corporation: Forest potential, productivity and value. Weyerhauser Sci. Symposium 4, Weyerhauser Corporaration, Tacoma, Washington.

Graumlich, L.J. and L.B. Brubaker. 1986. Reconstruction of annual temperature (1590-1979) for Longmire, Washington, derived from tree rings. Quaternary Res. 25: 223-234.

Green, R.N. and P. Bernardy. 1991. Natural regeneration failure at high elevations in the Chipmunk Creek drainage, Chilliwack Forest District. Res. Memo 59, BC. Min. For. Victoria, BC. 3 pp.

Green, R.N. and K. Klinka. 1994. A field guide to site identification and interpretation for the Vancouver Forest Region. BC. Min. For., Victoria, BC. 285 pp.

Green, R.N., R.L. Trowbridge, and K. Klinka. 1993. Towards a taxonomic classification of humus forms. For. Sci. Monog. 29 (supplement to For. Sci. 39).

Grier, C.C., K.M. Lee, N.M. Nadkarni, G.O. Klock, P.J. Edgerton. 1989. Productivity of forests of the United States and its relation to soil and site factors and management practices: a review. Gen. Tech. Rep. PNW-GTR-222, USDA For. Serv., Pacific Northwest Res. Stn., Portland Oregon. 51 pp.

von Hahn, H. 1975. Artificial and natural regeneration in the Chilliwack Provincial Forest. Unpublished Rep., BC. For. Serv., Vancouver, BC. 13 pp.

Hale, M.E. Jr. and W.L. Culbertson. 1970. A fourth checklist of the lichens of the continental United States. The Bryologist 73:499-543.

Harris, A.S. 1969. Alaska-cedar, a bibliography with abstracts. Res. Paper PNW-73, USDA For. Serv., Pacific Northwest For. and Range Exp. Stn., Portland, Oregon. 47 pp.

Heinselman, M.L. 1981. Fire and succession in the conifer forests of northern North America. Pp. 374-405 in D.C. West, H.H. Shugart, and D.B. Botkin. (eds.): Forest succession: concepts and application. Springer-Verlag, New York, N.Y..

Herring, L.J. and D.E. Etheridge. 1976. Advance amabilis fir regeneration in the Vancouver Forest District. BC. For. Serv. and Can. For. Serv. Joint Rep. 5. Pacific Forest Research Centre, Victoria, BC. 23 pp.

Hill, M.O. 1979. TWINSPAN - a FORTRAN program for arranging multivariate data in an ordered two-way table by classification of the individuals and attributes. Cornell University, Ithaca, N.Y.

Hills, G.A. and G. Pierpoint. 1960. Forest site evaluation in Ontario. Res. Rpt. 42, Ont. Dept. of Lands and Forests, Toronto, Ontario. 66pp.

Holland, S.S. 1976. Landforms of British Columbia. A physiographic outline. 2nd ed. BC. Dep. Mines Mineral Resources, Bull. No. 48. Victoria, BC. 138 pp.

Hoyer, G.E. and R. Chawes, 1980. Application of Zeide´s standardized growth curves and the two-point curve form estimation system to Pacific Northwest species. State of Washington Dep. Natur. Resour. Rep. No. 40. 19 pp.

Hoyer, G.E. and F.R. Herman. 1989. Height-age and site index curves for Pacific silver fir in the Pacific Northwest. USDA Res. Pap. PNW-RP-418. Pacific Nortwest Research Stn., Portland Oregon.

Husted, L.D. 1982. The relationship between foliar and soil chemistry, growth parameters, and variable height growth in advance regneration of amabilis fir. M.Sc. Thesis, Univ. of British Columbia, Vancouver, BC. 125 pp.

Ireland, R.R., C.D. Bird, G.R. Brassard, W.B. Schofield and D.H. Vitt. 1987. Checklist of the mosses of Canada II. Lindbergia 13:1-62.

Jenny, H. 1941. Factors of soil formation. McGraw-Hill Book Co., New York, N.Y. 281pp.

Kimmins, J.P. 1989. The scientific foundations for the simulation of ecosystem function and management in Forcyte 11. Unpublished Rep., For. Sci. Dept., Univ. British Columbia, Vancouver, BC. 201 pp.

Klinka, K. 1977. Guide for the tree species selection and prescribed burning in the Vancouver Forest District. BC. For. Serv., Vancouver, BC. 49 pp.

Klinka, K. and R.E. Carter. 1991. A stand-level guide to the selection of reproduction methods for regenerating forest stands in the Vancouver Forest Region. Contract Rep., BC. Min. For., Burnaby, BC. 19 pp.

Klinka, K., and R.E. Carter. 1990. Relationships between site index and synoptic environmental variables in immature coastal Douglas-fir stands. For. Sci. 36: 815-830.

Klinka, K., R.E. Carter, G.F. Weetman and M. Jull. 1992. Silvicultural analysis of the subalpine mountain hemlock forest. Contract report for BC Ministry of Forests, unpublished.

Klinka, K. and V.J. Krajina. 1986. Ecosystems of the University of British Columbia Research Forests, Haney, BC., Univ. of British Columbia, Vancouver, BC. 123 pp.

Klinka. K. and F.T. Pendl. 1976. Problem analysis of reforestation in high elevations in the Vancouver Forest District. Unpublished Rep., BC. For. Serv., Vancouver, BC. 107 pp.

Klinka, K., Q. Wang, and R.E. Carter. 1990a. Relationships among humus forms, forest floor nutrient porperties, and understory vegetation. For. Sci.: 36: 564-581.

Klinka, K., J. Pojar, and D.V. Meidinger, 1991. Revision of biogeoclimatic units of coastal British Columbia. Northwest Sci. 65: 32-47.

Klinka, K., R.E. Carter, and M.C. Feller. 1990c. Cutting old-growth forests in British Columbia: ecological consideration for forest regeneration. The Northwest Environmental Journal 6: 221-242.

Klinka, K., F.C. Nuszdorfer, and L. Skoda. 1979. Biogeoclimatic units of central and southern Vancouver Island. BC., BC Min. For., Victoria, BC. 120 pp.

Klinka, K., R.N. Green, P.J. Courtin, and F.C. Nuszdorfer. 1984. Site diagnosis, tree species selection, and slashburning guidelines for the Vancouver Forest Region. Land Manage. Rep. 25, BC. Min. For., Victoria, BC. 180 pp.

Klinka, K., V.J. Krajina, A. Ceska, and A.M. Scagel. 1989. Indicator plants of coastal British Columbia. University of British Columbia Press, Vancouver, BC. 288 pp.

Klinka, K., H. Qian, J. Pojar and D.V. Meidinger. 1996. Classification of natural forest communities of coastal British Columbia. Vegetatio 125:149-168.

Klinka, K., J. Worrall, L. Skoda and P. Varga. 2000. The distribution and synopsis of ecological and silvical characteristics of tree species of British Columbia's forests. Canadian Cartographics Ltd. Coquitlam, BC. 180 pp.

Klinka, K., Q. Wang, G. Kayahara, R.E. Carter, and B.A. Blackwell. 1992. Light-growth response in Pacific silver fir and subalpine fir. Can. J. Bot. 70:1919-1930.

Klinka, K., M.C. Feller, R.N. Green, D.V. Meidinger, J. Pojar, and J. Worrall. 1990b. Ecological principles: applications. Pp. 55-72 in D.P. Lavender, R. Parish, C.M. Johnson, G. Montgomery, A. Vyse, R.A. Willis, and D. Winston. (eds.): Regenerating British Columbia's forests. Univ. British Columbia Press, Vancouver, BC.

Krajina, V.J. 1933. Die Pflanzengesellschaften des Mlynica-Tales in den Vysoke Tatry (Hohe Tatra). Mit besonderer Berücksichtigung der ökologischen Verhältnisse. Bot. Centralbl., Beih., Abt. 2, 50: 744-957, 51: 1-244. [*in German*]

Krajina, V.J. 1959. Biogeoclimatic zones in British Columbia. Bot. Ser. No. 1, Dept. Bot., University of British Columbia, Vancouver, BC.

Krajina, V.J. 1965. Biogeoclimatic zones in British Columbia. Ecol. Western N. Amer. 1: 1-17.

Krajina, V.J. 1969. Ecology of forest trees in British Columbia. Ecol. Western N. Amer. 2: 1-146.

Krause, H.H., G.F. Weetman, and P.A. Arp. 1978. Nutrient cycling in boreal forest ecosystems of North America. Pp. 287-314 in C.T. Youngberg (ed.): Forest soils and land use. Oregon State Univ. Press, Corvallis Oregon.

Krumlik, G.J. 1979. Comparative study of nutrient cycling in the subalpine Mountain Hemlock zone of British Columbia. Ph.D. Thesis, Univ. of British Columbia, Vancouver, BC. 196 pp.

Kubiëna, W.L. 1953. The soils of Europe. Thomas Murby and Company, London, UK.

Kuruzc, J.F. 1982. Polymorphic site-index curves for balsam-*Abies amabilis* in coastal British Columbia. Mac-Millan Bloedel LTD., Woodlands Serv. Div., Nanaimo, BC. Res. Proj. 933-3.

Larsen, C.P.S., and G.M. MacDonald. 1995. Relations between tree-ring widths, climate, and annual area burned in the boreal forest of Alberta. Can. J. For. Res. 25: 1746-1755.

Lavkulich, L.M. and K.W.G. Valentine. 1986. The Canadian system of soil classification. In K.W.G. Valentine, P.N. Sprout, T.E. Baker, and L.M. Lavkulich (eds.). The soil landscapes of British Columbia. BC. Min. Env., Victoria, BC. pp. 59-65.

Lertzman, K.P. 1989. Gap-phase dynamics in a subalpine old-growth forest. Ph.D. Thesis, Univ. of British Columbia, Vancouver, BC. 167 pp.

Lewis, T. 1982. Ecosystems of the Port McNeill Block (Block 4) of Tree Farm Licence 25. Contract Rep., Western Forest Products Ltd, Vancouver, BC. 54 pp.

Lewis, T. 1985. Ecosystems of Quatsino Tree Farm License (TFL 6). Contract Rep., Western Forest Poducts Ltd, Vacouver, BC. 75 pp.

Little, E.L. Jr. 1979. Checklist of United States trees. USDA For. Serv., Agr. Handb. No. 541, Washington, D.C.

Lousier, J.D. 1990. Snag management in silvicultural operations. Silviculture Branch, BC. Min. For., Victoria, BC. 78 pp.

Luckman, B.H. 1997. Developing a proxy climate record for the last 300 years in the Canadian Rockies - some problems and opportunities. Climatic Change 36: 455-476.

Luttmerding, H.A., D.A. Demarchi, E.C. Lea, D.V. Meidinger, and T. Vold. (eds.) 1990. Describing ecosystems in the field. 2nd Ed. BC. Min. For., Victoria, BC.

Magurran, A.R. 1988. Ecological diversity and its measurement. Princeton Univ. Press, Princeton, New Jersey.

Major, J. 1951. A functional, factorial approach to plant ecology. Ecology 32:392-412.

Martin, W. 1985. Post-clearcutting forest floor nitrogen dynamics and regeneration response in the Coastal Western Hemlock wet subzone. Ph.D. Thesis, Univ. British Columbia, Vancouver, BC. 350 pp.

Matson, W.H. and R.D. Boone. 1985. Natural disturbance and nitrogen mineralization: wave-form dieback of mountain hemlock in the Oregon Cascades. Ecology 65: 1511-1516.

McVean, D.N. and D.A. Ratcliffe. 1962. Plant communities of the Scottish highlands. A study of Scottish mountain moorland and forest vegetation. Monog. Nature Conservancy, No. 1. London, UK.

Meidinger, D.V. and J. Pojar. (eds.) 1991. Ecosystems of British Columbia. Special Rep. Series No. 6, BC. Min. For., Victoria, BC.

Messier, C.M. and J.P. Kimmins. 1990. Factors limiting coniferous seedling growth in recently clearcut sites dominated by *Gaultheria shallon* in the CWHvm subzone. FRDA Rep. 149, BC. Min. For., Victoria, BC. 30 pp.

Milner, K.S. 1988. Constructing site specific height growth curves. In IUFRO forest growth modelling and prediction conf. USDA For. Serv. Gen. Tech. Rep. NC-120. 1149 pp.

Monger, J.W.H. and J.M. Journeay. 1994. Guide to the geology and tectonic evolution of the southern Coast Mountains. Geol. Survey of Canada Open File 2490, Vancouver, BC. 77 pp. plus maps.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley and Sons, Toronto, Ontario.

Murray, M.D., D. Cobble, and R.O. Curtis. 1991. Height gowth of young Pacific silver fir and noble fir established on clearcuts in the Pacific silver fir zone of western Washington. Can. J. For. Res. 21: 1213-1221.

Nordhagen, R. 1937. Versuch einer neuen Einteilung der subalpinen-alpinen Vegetation Norwegens. Bergens Mus. Arbok, Naturv. Rekke 1937(1936): 1-88. [*in German*]

Oliver, C.D. and B.C. Larson. 1990. Forest stand dynamics. McGraw-Hill, Inc., New York, N.Y.. 467 pp.

Orloci, L. 1965. The Coastal Western Hemlock Zone on the southwestern British Columbia mainland. In V.J. Krajina (ed.). Ecology of Western North America, Vol. 1. Univ. Brit. Col., Vancouver, pp. 18-34.

Peterson, E.B. 1969. Radiosonde data for characterization of a mountain environment in British Columbia. Ecology 50(2): 200-205.

Pojar, J. and A. MacKinnon. 1994. Plants of coastal British Columbia including Washington, Oregon, and Alaska. Lone Pine Publishing, Vancouver, BC. 528 pp.

Pojar, J., K. Klinka, and D.A. Demarchi. 1991. Mountain Hemlock zone. In D. Meidinger and J. Pojar (eds.). Spec. Rep. Series 6, BC. Min. For., Victoria, BC., pp. 113-124.

Pojar, J., Klinka, K., and Meidinger, D. V. 1987. Biogeoclimatic ecosystem classification in British Columbia. For. Ecol. Manage. 22: 119-154.

Poore, M.E.D. 1962. The method of successive approximation in descriptive ecology. Adv. Ecol. Res. 1: 35-68.

Qian, H., K. Kinka, and B. Sivak. 1997. Diversity of the understory vascular vegetation in 40 year-old and old-growth forest stands on Vancouver Island, British Columbia. J. Veg. Sci. 8:773-780.

Rauscher, H.M. 1984. Homogeneous macroclimatic zones of the Lake States. USDA For. Serv. Res. Pap. NC-240. North Central For. Exp. Stn., St. Paul, Minnesota.

Reuter, F. 1973. High elevation reforestation problems in the Vancouver Forest District. Contract Rep., BC. For. Serv., Victoria, BC. 46 pp.

Rodwell, J.S. (ed.) 1991. British plant communities. Vol. 1. Cambridge University Press, Cambridge, UK.

Rose, M.F. and C. Grant. 1976. Remote station climate prediction model. Environment and Land Use Committee Secretariat, (ELUC) , Data Services Division, Victoria, BC. 8pp.

Ryder, J.M. 1986. Geology, landforms and surficial materials. In K.W.G. Valentine, P.N. Sprout, T.E. Baker, and L.M. Lavkulich (eds.). The soil landscapes of British Columbia. BC. Min. Env., Victoria, BC. pp. 11-33.

Scagel, R., R. Green, H. von Hahn, and R. Evans. 1989. Exploratory high-elevation regeneration trials in the Vancouver Forest Region: 10-year species performance of planted stock. FRDA Rep. 098, BC. Min. For., Victoria, BC. 40 pp.

Schaefer, D.G. 1986. Climate. In K.W.G. Valentine, P.N. Sprout, T.E. Baker, and L.M. Lavkulich (eds.). The soil landscapes of British Columbia. BC. Min. Env., Victoria, BC. pp. 3-10.

Schweingruber, F.H., K.R. Briffa, and P.D. Jones. 1991. Yearly maps of summer temperatures in western Europe from A.D. 1750 to 1975 and western North America from 1600 to 1982: Results of a radiodensitometrical study on tree rings. Vegetatio 92: 5-71.

Scott, D.R.M, J. Long, and J. Kotar. 1976. Comparative ecological behaviour of western hemlock in the Washington Cascades. Pp. 26-33 in W.A. Atkinson and R.J. Zasoski (eds.): Proceedings of Western Hemlock Management Conference. Univ. Washington, Seattle, Washington.

Shimwell, D.W. 1971. The description and classification of vegetation. Univ. Washington Press, Seattle, Washington.

Silviculture Branch. 1990. First approximation of correlated guidelines for free growing stocking standards for the ecosystems of British Columbia. BC. Min. For., Victoria, BC. 12 pp.

Smith, D.M. 1986. The practice of silviculture. 8th Ed. John Wiley & Sons, New York, N.Y. 527 pp.

Splechtna, B.E. 1999a. New Height Growth and Site Index Models for Pacific Silver Fir in Southwestern British Columbia Scientia Silvica Extension Series Number 19. For. Sci. Dept., Univ. of British Columbia, Vancouver, BC. ISSN 1209-952X.

Splechtna, B.E. 1999b. Quantitative Characterization of Nutrient Regimes in Coastal Subalpine Soils of British Columbia. Scientia Silvica Extension Series Number 21. For. Sci. Dept., Univ. of British Columbia, Vancouver, BC. ISSN 1209-952X.

Splechtna, B.E. 1999c. Pacific silver fir site index in relation to ecological measures of site quality. Scientia Silvica Extension Series Number 20. For. Sci. Dept., Univ. of British Columbia, Vancouver, BC. ISSN 1209-952X.

Stotler, R. and B. Crandall-Stotler. 1977. A checklist of the liverworts and hornworts of North America. The Bryologist 80:405-428.

Taylor, R.L. and B. MacBryde. 1977. Vascular plants of British Columbia. Tech. Bull. No. 4. Univ. British Columbia Press, Vancouver, BC.

Thrower, J.S. and J.W. Goudie. 1992. Development of height-age and site-index functions for even-aged interior Douglas-fir in British Columbia. BC. Min. For. Research Note No. 109. Victoria, BC.

Trewartha, G.T. 1968. An introduction to climate. 4th edition. McGraw-Hill, New York, N.Y.

Ugolini, F.C. 1982. Soil development in the *Abies amabilis* zone of the central Cascades. Pp. 165-176 in C.D. Oliver and R.M. Kenady (eds.): Proceedings of the symposium on the biology and management of true firs in the Pacififc Northwest. Contribution No. 45, Univ. Washington, Seattle, Washington.

Ugolini, F.C. and D.H. Mann. 1979. Biopedological origin of peatlands in south east Alaska. Nature 281: 336-368.

Utzig, G. and L. Herring. 1974. Factors significant to high-elevation forest management. Unpublished Rep., BC. For. Serv. Victoria, BC. 69 pp.

Utzig, G. and L. Herring. 1975. Forest harvesting impacts at high elevations: five case studies. Res. Note No. 72, BC. For. Serv., Victoria, BC. 85 pp.

Viereck, L.A., C.T. Dyrness, A.R. Batten, and K.J. Wenzlick. 1992. The Alaska vegetation classification. USDA For. Serv. Gen. Tech. Rep. PNW-GTR-286, Portland, Oregon.

Vogt, K., E. Moore, S. Gower, D. Vogt, D. Sprugel, and C. Grier. 1989. Productivity of upper slopes Forests in the Pacific Northwest. Pp. 137-163 in D.A. Perry, R. Meurisse, R. Miller, J. Boyle, J. Means, C.R. Perry, and R.F. Powers (eds.): Maintaining the long-term productivity of Pacific Northwest forest ecosystems. Timber Press, Portland, Oregon.

Wade, L.K. 1965. Vegetation and history of the *Sphagnum* bogs of the Tofino area, Vancouver Island. M.S. Thesis, Univ. of British Columbia, Vancouver, BC.

Wagner, R. 1980. Natural regeneration at the edge of an Abies amabilis zone clearcut on the west slope of central Washington Cascades. M.Sc. Thesis, Univ. Washington, Seattle, Washington. 72 pp.

Wang, G.G. 1993. Ecological site quality, site index, and height growth of white spruce stands in the Sub-Boreal Spruce zone of British Columbia. Ph.D. Thesis, Univ. of British Columbia, Vancouver, BC. 207pp.

Wang, Q. 1992. Ecological and height growth analysis of some sub-boreal immature lodgepole pine stands in central British Columbia. Ph.D. Thesis, Univ. of British Columbia, Vancouver, BC. 207 pp.

Wang, G.G. and K. Klinka. 1995. Site specific height curves for white spruce stands based on stem analysis and site classification. Ann. Sci. For. 52:607-618.

Wang,G.G., P.L. Marshall, and K. Klinka. 1994. Height growth pattern of white spruce in relation to site quality. For. Ecol. Manage., 68:137-147.

Weetman, G.F, 1989a. Foliar analysis and response of fertilized chlorotic Sitka spruce plantations on salal-dominated cedar hemlock cutovers on Vancouver Island. Can. J. For. Res. 19: 1501-1511.

Weetman, G.F, 1989b. Foliar analysis and response of fertilized chlorotic western hemlock and and western redcedar reproduction on salal-dominated cedar-hemlock cutovers on Vancouver Island. Can. J. For. Res. 19: 1512-1520.

Weetman, G.F., R. Fournier, E.S. Panozzo, and J. Barker. 1990. Post-burn nitrogen and phosphorus availability of deep humus soils in coastal British Columbia cedar/hemlock forests and the use fertilization and salal eradication to restore productivity. Pp. 415-499 in S.P. Gessel, D.S. Lacate, G.F. Weetman, and R.F. Powers (eds.): Sustained producivity of forest soils. Fac. For., Univ. British Columbia, Vancouver, BC.

Westhoff, V., and E. van der Maarel, 1980. The Braun-Blanquet approach. In: Classification of Plant Communities. Edited by R. H. Whittaker. Dr. W. Junk bv Publishers, The Hague, Netherlands.

Whittaker, R.H. 1975. Communities and ecosystems. Macmillan Pub. Inc., New York, N.Y.

Williams, C.B., Jr. and J.F. Franklin. 1965. Pacific silver fir, a bibliography with abstracts. Res. Pap. PNW-21, USDA For. Serv., Pacific Northwest For. and Range Exp. Stna., Portland, Oregon. 84 pp.

Yarie, J. 1978. The role of understory vegetation in the nutrient cycling of forested ecosystems in the Mountain Hemlock biogeoclimatic zone. Univ. British Columbia, Vancouver, BC. 176 pp.

Yorath, C.J. and H.W. Nasmith. 1995. The geology of southern Vancouver Island: a field guide. Orca Book Publishers, Victoria, BC. 172 pp.