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ECOLOGY AND MANAGEMENT OF INTERIOR DOUGLAS-FIR *(PSEUDOTSUGA MENZIESII VAR GLAUCA)* AT THE NORTHERN EXTREME OF ITS RANGE

PROCEEDING OF A WORKSHOP HELD 7-9 OCTOBER 1996,
IN FORT ST. JAMES, BRITISH COLUMBIA

J. Daniel Lousier, Ph.D and Winifred B. Kessler, Ph.D, editors

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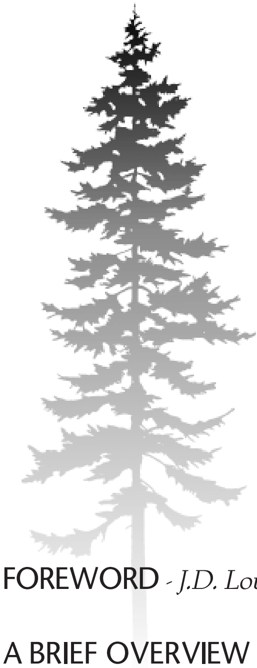

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FOREWORD

J.DANIEL LOUSIER AND WINIFRED KESSLER

FOREWORD

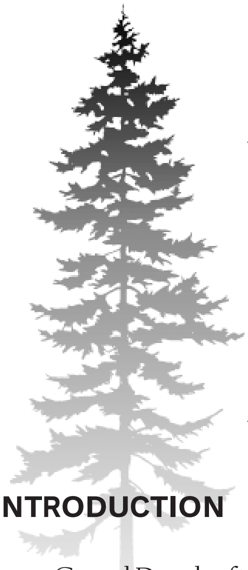
Within the Prince George TSA, interior Douglas-fir reaches the northern edge of its natural range in British Columbia. A number of long-time residents and forest workers in the area have noted that the amount and distribution of Douglas-fir on these northern landscapes appear to be decreasing. In the 1950s and 60s, harvesting and milling of Douglas-fir was much more prevalent than they are today. Because of the scattered nature of Douglas-fir forest types and the unique values attributed to them as ecosystem components, the perceived reduction in Douglas-fir forest types has generated a considerable level of concern. This problem analysis was undertaken to address five key areas of concern. They are:

- Is Douglas-fir a diminishing component of our landscape? Do we have adequate data to assess this condition?
- What is the ecological, cultural, and economic significance of this resource to the area? What might be the implications of changes in the resource?
- Is the Douglas-fir resource an example of management by design or default? What policy and long-term goals are needed to sustain the resource?
- What is required to define management goals and strategic directions?
- What is needed to successfully regenerate Douglas-fir on the landscape?

Douglas-fir management has been a growing issue among management agency and industry staff for a number of years. The issue has been identified as a high priority need in the Fort St. James Forest District, and has relevance to the Vanderhoof and Prince George Forest Districts as well. While Douglas-fir is harvested on several sites in these three districts, historically there has been little planting of Douglas-fir in the Prince George Forest Region. There is considerable concern over the limiting or elimination of Douglas-fir in those ecosystems in which it is a co-dominant species, or a secondary or tertiary species. To address these concerns in the Fort St. James Forest District, the district policy is, for example, to replant Douglas-fir on areas from which it was harvested, and one of the objectives of the Fort St. James Land Resource Management Plan (LRMP) is to maintain and enhance Douglas-fir on all appropriate sites.

This project identified the main ecological functions and values of northern Douglas-fir ecosystems, thoroughly reviewed the past and present Douglas-fir management practices in north-central British Columbia, reviewed the ecology and management of Douglas-fir in southern British Columbia and the Pacific coast, and assessed briefly the socio-economic and cultural dimensions of the Douglas-fir resource. This project also fostered bridging among the field operational community, management agencies, and the academic world. The operational forestry community generously contributed their time to provide an immense amount of important, practicable, and relevant information which forms the basis of the interim management plan. We were able to draw on local, provincial and international experts to provide us with the 'state of the art and science' of Douglas-fir management throughout western North America, and to help us in the workshop to develop the management strategies included in the interim management plan. For these generous contributions, we are grateful.

We are also grateful to the staff of Madrone Consultants Ltd. in Prince George for their work in organizing and delivering the workshop: Christina Pendergast, Dan Lousier, Rhian Evans, Leisbet Beaudry and Caroline Whittaker.



A BRIEF OVERVIEW OF COASTAL DOUGLAS-FIR ECOSYSTEMS

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INTRODUCTION

Coastal Douglas-fir, ***Pseudotsuga menzeisii*** var. ***menziesii,*** ranges from coastal British Columbia (51° N) south to central California, and from the Pacific Ocean to the east slopes of the Cascades and Sierra Madre. Western Oregon and Washington account for 75% (by area) of coastal Douglas-fir forests, western British Columbia 14%, and California 11% (Oswald *et al.* 1986). Tall and straight-boled, with old-growth stands accumulating massive amounts of volume per hectare, coastal Douglas-fir was for many years the most important timber tree in western North America, and one of the most important in the United States. During the 1970s, Douglas-fir from western Oregon and Washington accounted for more than 50% of all softwood produced in the western United States and 25% of that produced by the entire Nation (Oswald *et al.* 1986).

Douglas-fir, especially old growth, also has numerous biological, social, and aesthetic values not protected by management focused on timber production. Old-growth provides prime habitat for numerous species (more on this later), including two, the spotted owl and the marbled murrelet, now protected under the United Stateds Endangered Species Act (ESA). Impacts on streams due to logging and road building have contributed to salmonid declines in the region (Everest *et al.* 1985, Beshta 1991, Nehlsen *et al.* 1992). In 1992, the American Fisheries Society listed 214 stocks of anadromous salmon as "depleted" in Oregon, Idaho, Washington, and California, including 101 stocks deemed high risk for extinction (Nehlsen *et al.* 1992) (various factors are involved in salmonid declines, but stream degradation is clearly one of those). Coho stocks from the coastal rivers of Oregon and northern California may soon be listed under the ESA, although the Governor of Oregon is trying to head this off by developing a state conservation plan.

Aesthetically, old-growth Douglas-fir forests are not only among the last pristine old-growth remaining in the lower 48 states (hence invoking a cardinal rule of economics : scarce resources become more valuable), their sheer massiveness invokes awe that eludes description (except perhaps by poets), and must be experienced to be understood.

In a series of lawsuits brought by environmental groups during the late 1980s and early 1990s Federal courts in Oregon and Washington ruled the US Forest Service and Bureau of Land Management (which together manage about 50% of coastal Douglas-fir forests in the US) were not in compliance with the nation's environmental laws, and additionally compelled the US Fish and Wildlife Service to list the spotted owl under the ESA (Booth 1994 gives an excellent history of the struggle between utilization and environmental protection in the Douglas-fir region). These rulings brought timber harvest from federal lands in the coastal Douglas-fir region to a virtual halt, and triggered a series of planning efforts culminating in one of the earliest initiatives of Bill Clinton's first term, a presidentially-mandated gathering of scores of scientists and managers over a several month period, resulting in the Pacific Northwest Plan to balance economics and environmental values on federal lands in the coastal Douglas-fir region.

Controversy and change in the coastal Douglas-fir region has not been restricted to the US. During the same period in British Columbia, public opposition (international as well as national) over logging practices in the Douglas-fir, western redcedar, and hemlock forests on Vancouver Island led to establishment of the Scientific Panel for Sustainable Practices in Clayoquot Sound, whose goal was to "... recommend standards that maintained the full spectrum of forest values and explicitly incorporated First Nations' perspectives" (Clayoquot Sound Scientific Panel 1995).

With this brief historical background, I turn now to discuss ecological and silvicultural aspects of this unique tree, which in many respects has been the focal point for a world-wide re-evaluation of the practice of forestry and forestry's role in modern society. I will close with some reflections on what we have learned in the Pacific Northwest, and how others might avoid the traps we fell into.

ECOLOGY

HABITAT

Coastal Douglas-fir has wide ecological amplitude, occupying a variety of habitats within its range. It is seral to Sitka spruce in a narrow coastal band, to western hemlock in the low and mid-elevations of the Coast Range and Cascades, and to Pacific silver fir at higher elevations in the Cascades and Coast Ranges.

Douglas-fir is a major component of the mixed conifer forests of southwestern Oregon and California, and in relatively dry sites of that area forms climax stands. Either as a major or minor (occasional) component, Douglas-fir can occur in virtually every forest type west of the Cascades crest (Franklin and Dyrness 1973). Common associates on mesic sites include western hemlock, western redcedar, grand fir, Pacific yew, vine maple, and bigleaf maple. The mixed conifer/hardwood forest types of southern Oregon and northern California are among the most diverse in North America, and in these Douglas-fir may associate with more than a score of other tree species.

PRODUCTIVITY

Along with other Pacific Coast conifers, Douglas-fir has great longevity, individuals living from several hundred to over a thousand years (depending on site), attaining heights of 50 to over 100 m and diameter at breast height from 1 to 3 m. Individual old-growth trees may have 4000 m^2 leaf surface distributed over 60 to 70 million needles (Pike *et al.* 1977). Growth rates are relatively high, though in the first few decades they may be equalled or surpassed by southern pines and perhaps some other North American species. Oswald *et al.* (1986) estimate that 60% of fully stocked, unmanaged stands produce at least 8.4 m^3/ha/yr.

Few North American tree species can sustain high growth rates for as long as Douglas-fir, and none outside of the Pacific coastal zone (with the possible exception of ponderosa pine). In a 10-year study of a 250-year-old stand in the Oregon Cascades, annual net wood increment averaged 15.8 m^3/ha, and gross wood increment (living plus mortality) averaged 29.9 m^3/ha (Bernsten 1960; mortality was unusually high during that period because of a major windstorm and subsequent bark beetle outbreak). Due to sustained growth over centuries, Douglas-fir forests accumulate greater biomass than any forest type other than redwood (and perhaps some of the giant conifers of southern Chile). Old-growth stands on mesic sites commonly have over 100 m^2/ha basal area, 800 to 900 t/ha live above ground biomass, and 2000 m^3/ha wood volume. Maximum above ground living biomass is on the order of 1600 t/ha (Franklin and Dyrness 1973). Stands also accumulate large amounts of coarse woody debris (CWD; snags and logs > 10 cm in diameter). In the western Cascades, 22 stands 200 years or older averaged 116 t/ha CWD, 16 of which had greater than 200 t/ha (Harmon *et al.* 1986). Except for other Pacific coast conifers, these values far exceed any recorded in other forest types throughout the world.

DISTURBANCE AND STAND DEVELOPMENT

Most disturbances common to other forest types also occur in coastal Douglas-fir: pathogens, bark beetles, wind, and fire. In contrast to Douglas-fir on the east slopes of the Cascades and interior mountains, outbreaks of defoliating insects are so rare as to be virtually nonexistent west of the Cascades crest. The reason for the difference east and west of the Cascades crest is unclear (the insects are present west of the crest), but probably relates to environment rather than inherent differences between the coastal and interior varieties of Douglas-fir. In fact, foliage from trees west of the Cascades crest is more palatable to spruce budworm than that from trees east of the crest (Perry and Pitman 1983). Douglas-fir bark beetle will occasionally outbreak and kill large numbers of trees, but this is usually associated either with extended drought or infrequent large windthrow.

Root rots are fairly common, especially laminated root rot, black stain root rot, and *Armillaria*. Laminated root rot, in particular, is a great diversifying agent, creating gaps in the Douglas-fir canopy that are often occupied by resistant hardwoods. Some pathologists believe that laminated root rot is more severe in plantations than in unmanaged forest, because cutting followed by planting increases exposure of seedlings to infected roots (Wald Theis, personal communication). A native foliar pathogen, Swiss needle cast, is currently at epidemic levels in Douglas-fir plantations along the Oregon coast, a phenomenon not seen in the past and probably stemming in part, at least, from the extensive area of plantations created in that area.

As with most western conifer forests, fire has historically been the primary disturbance agent in Douglas-fir forests. As elsewhere, the historic fire regime varies widely depending on ignition sources and environment. In moister areas such as the Olympic Mountains, fires were infrequent and severe, while in drier areas such as the Klamath Province they were frequent and relatively gentle (Agee 1991). After Euro-American settlement in the mid 1800s, large fires became more common, and many of the mature stands existing today derived from these anthropogenic burns.

Mature and old-growth (OG) trees are relatively resistant to fires (Agee 1991). That, coupled with the fact that intact OG forests maintain higher humidity and soil moisture than young forests, makes OG more resistant than young forests to stand-destroying fires (Perry 1988; Franklin *et al.* 1989). Plantations and younger, densely-stocked natural stands are highly susceptible to crown fires, and may propagate fire into the crowns of OG islands in their midst. One implication of this dynamic is that extensive conversion from older to younger forests has converted a landscape that by virtue of its dominance by OG tended to dampen the spread of crown fires, to one that magnifies the spread of crown fires (Perry 1988, 1995; Franklin *et al.* 1989).

Until recently, stand development following fire was believed to follow the standard Oliver model: a short period of openness, followed by crown closure, stem exclusion (density-related mortality), and then OG (Oliver 1981). However, accumulating evidence indicates that at least some, and perhaps many OG stands did not go through a stem exclusion phase, but rather were open-grown for relatively long periods following establishment, with periodic recruitment of new age classes. Work during the late 1960s and early 1970s showed that OG stands in the Cascades (at least those studied), were uneven-aged. A stand on the HJ Andrews Research Forest (HJA) (70 km east of Eugene Oregon) contained Douglas-fir ranging from 75 years to 570 years old (Franklin and Waring 1979). Tallied in 10-year classes, this stand had 14 different age classes between 375 years and 540 years old. Another stand on the HJA had 20 ten-year age classes between 350 and 470 years old, and an OG stand in the Wind River Valley of the Washington Cascades contained 21 ten-year age classes between the ages of 230 and 460 years (Franklin and Waring 1979). While some younger age classes were probably established by light to moderate burns or blowdown, the weight of evidence indicates that Douglas-fir trees establish over decades and perhaps centuries following stand destroying fires. Stand reconstruction in the Coast Range and Siskiyou Mountains shows similar patterns: what are now OG trees established at low densities (50 to 125 stems per ha in both areas), in some cases went through a short period (<20 years) of slow growth, then entered a sustained period of very rapid growth (Tappeiner *et al* in press, Sensenig unpublished). The picture that emerges is that of a structurally complex community of Douglas-fir and perhaps other conifers intermixed with hardwood trees and shrubs. Because many hardwood species in the region do not readily burn and in mixed stands block flames from moving into conifer crowns (Perry 1988), such stands would have been more resistant to fire than the densely-stocked pure conifer stands that fill today's landscape. They also would have been more resistant to conifer-specific pathogens, such as laminated root rot.

DIVERSITY

Forests west of the Cascades crest support a diverse terrestrial fauna. Western Oregon and Washington forests are home to 460 vertebrate species, including 260 bird species, 138 mammals, 32 amphibians, and 23 reptiles (Brown 1985). Invertebrate and fungal species number in the tens of thousands. On the HJA, more than 3400 arthropod species have been documented, compared to 460 vascular plant species and 143 vertebrate species (Lattin 1990). Voegtlin (1982) collected 1500 arthropod taxa from the crowns of three OG trees on the HJA. Lattin (1990, 1993) estimates the number of arthropod species on the HJA totals 6000 to 8000. Speaking of mature and OG Douglas-fir, Moldenke and Lattin (1990) argue "*. . .* it is quite probable that the highest levels of terrestrial diversity anywhere on earth occur in the soils of our temperate forests."

Litter and soil are especially important habitats for arthropods and other invertebrates that play key roles in the nutrient cycle. A square meter of forest floor and mineral soil in OG forests on the HJA averages 250 arthropod species, including roughly 250,000 individual oribatid mites in 75-100 species and 50,000 springtails in 20-30 species, values that "*. . .* approximate or exceed diversities reported from any ecosystem in the world" (Moldenke and Lattin 1990). The fungal community is equally diverse, comprising saprophytes, mycorrhiza-formers, foliar endophytes, and a few pathogenic species. Trappe (1977) estimates that 2000 species of fungi are mycorrhizal with Douglas-fir alone.

Because traditional forest management truncates the late mature and OG states, concern over management impacts on diversity has focused primarily on species associated with older forests. A commonly accepted view in the Pacific Northwest, and indeed in conifer forests in general, is that species diversity and structural diversity are relatively high during early succession, decline with crown closure (Oliver's stem exclusion phase), then increase again during the OG phase (e.g., Harris and Maser 1984). While this is doubtless true for structural diversity (with some caveats I will discuss later), species richness is more complicated.

Some studies show either small or no differences in species richness of certain guilds among age classes of naturally established stands (e.g., Raphael 1991; Carey *et al.* 1991; Gilbert and Allwine 1991), while others show greater diversity in mature and OG forests [Ruggerio *et al* (1991a) contains an excellent collection of studies dealing with habitats in unmanaged Douglas-fir forests]. In Douglas-fir/hardwood forests of northern California, for example, Raphael and Marcot (1986) found greater vertebrate richness (especially breeding birds) in mature and OG than in younger stands. Comparisons between OG and plantations show greater diversity in the former. In the Siskiyou Mountains (southwest Oregon), Amaranthus *et al.* (1995) found 13 species of truffle-forming ectomycorrhizal fungi (EM) in OG Douglas-fir that were not present in plantations, and in the Cascades, O'Dell *et al.* (1992) found 12 EM species in OG Douglas-fir that did not occur in plantations, 4 of which did not occur in rotation-age stands. Schowalter (1989) documented 66 species of canopy arthropods on OG Douglas-fir in the HJ Andrews Experimental Forest, and only 15 species on trees in 7 to 11 year-old plantations. Schowalter also found significant differences between stand ages in structure—hence function—of the canopy arthropod community. The ratio of predatory to herbivorous arthropods (measured as biomass), a measure of food chain balance, was 0.89 in OG and only 0.14 in sapling stands. Schowalter found similar patterns in deciduous forests of the southern Appalachians, suggesting this may be a general pattern.

An important lesson from research on habitat needs in the Pacific Northwest is that species richness per se is not a good conservation goal; species differ in habitat requirements, and a shift in habitats may result in similar species richness but great changes in particular taxa and guilds. Moreover, abundance of a species in a particular habitat is a better gauge of the importance of that habitat than a simple measure of presence or absence (Raphael 1991). When abundance is used as a criterion, as was done by Lehmkuhl and Ruggiero (1991) and later by the Scientific Analysis Team (SAT 1993), a large number of species is seen to be closely associated with mature and OG forests of the Douglas-fir region, including 26 mammal species (of which 11 were bats, 38 bird species, 16 amphibians, 206 arthropods, 102 mollusks, 127 vascular plants, 157 lichens, 106 bryophytes (hornworts, liverworts, and mosses), and 527 fungi (SAT 1993, Marcot 1997).

Little is known about the absolute habitat requirements of many of these species (i.e., how fully dependent they are on OG); however, the approach taken in the Pacific Northwest is that it is reasonable and prudent to assume these species are threatened unless steps are taken to protect their current habitats and ensure new habitats will be generated in the future.

Some OG associates appear to find suitable habitat in young natural stands, a fact with considerable relevance to management. Researchers attribute this to the rich structural legacies left by natural disturbances (Hansen *et al.* 1991, Moldenke 1990, Franklin and Spies 1991, Carey *et al.* 1991). One of the central lessons of the past decade in the Pacific Northwest is the importance of biological legacies, such as living trees and large dead wood, in maintaining continuity of habitats and processes through successional stages. Low stocking density of conifers in naturally regenerating stands means the plant diversity and canopy complexity characteristic of many early successional stands (i.e., the shrub-sapling-forb-stage) were maintained for decades following natural disturbances, with some stands probably never going through a stem exclusion phase. Large dead wood, a primary legacy of natural disturbances, is especially important habitat for numerous vertebrate, invertebrate, and microbial species, and by virtue of its sponge-like water-holding capacity, plays an important role in processes such as nitrogen fixation (Harmon *et al.* 1986). The fact that large, decaying logs on the forest floor are commonly full of roots and mycorrhizae suggests that trees obtain water from logs during summer drought.

MANAGEMENT

Until the early 1990s, management in the Douglas-fir region was like forest management virtually everywhere; although lip service was paid to multiple use on public lands, timber was king. Except for a few reserves (mostly at high elevations), old growth was mined and converted to plantations. Planned rotations were far shorter than the potential life of the forest, with harvests scheduled before stands entered the stage of greatest biological diversity. The staggered setting approach to harvest, something like taking bites out of the middle of a pancake instead of from the edges, resulted in high road densities and increasing fragmentation of the mature and OG forests that did remain, diminishing their habitat value and leaving them vulnerable to wind and fire.

Mill capacity in the Pacific Northwest was encouraged to overbuild by two factors. First, future yields from managed stands were inflated by overly optimistic assumptions about growth gains from cultural treatments, and by underestimates of the vulnerability of plantations to fire and pathogens. Second, federal land managers and many policy analysts failed to account for the dramatic shift in national priorities toward greater environmental protection on public lands. Federal land management agencies, and even the US Fish and Wildlife Service (responsible for administering the Endangered Species Act), did not respond adequately to growing evidence that management direction was inconsistent with the nation's environmental laws (which were, and are, strongly supported by the public). Until the early 1990s, it was widely assumed that most remaining OG would be logged, despite the fact that as early as 1970 scientists were raising an alarm about potentially endangered species. New information simply outpaced the ability of large bureaucracies to overcome their considerable inertia and make meaningful changes.

In short, warning signals were ignored, and crisis resulted. The depth of the crisis should not be overestimated, however. While many timber-dependent communities were hurt, the economy of the region as a whole was the strongest in the US during the decade ending in 1994, a time in which the region transformed from dependence on a few resource extraction industries to a more broadly-based and healthy economy (PNWE 1995). In a 1995 consensus report endorsed by 64 Pacific Northwest economists, the health of the region's economy was attributed to the region's "livability," including in large measure its environmental values.

What have we learned from the events of the past 20 years in the Pacific Northwest? For one thing, that the rates and types of cutting common to modern forestry do not come close to mimicking natural disturbances and historic stand development patterns, and therefore should not be expected to protect native biodiversity (Franklin *et al.* 1989; Perry and Amaranthus 1997); we can't have our cake and eat it too! We have also learned that reserves alone are unlikely to protect species and other environmental values, especially when the reserves are selected because of low timber values rather than high biological values (Franklin 1993; Perry 1994). We have learned that landscapes filled with relatively homogeneous plantations are at greater risk to crown fires and pathogens than the natural forests they replaced (Perry and Amaranthus 1997).

By studying the structure and processes of native forests, we are learning that forestry done right and coupled with a good system of reserves can probably maintain healthy, fully functioning forest ecosystems. However, if optimism is justified, it is also important not to be pollyannish: ecosystems are exceedingly complex, and the depth of our ignorance calls for humility and respect. What "done right" means in any particular place is a matter of prudent experiment and continual learning, maintaining the options—and the will—to change as demanded by new information [in other words, adaptive management (Walters and Holling, 1990)].

Some principles are widely applicable, including the importance of planning at the scale of large landscapes, and of focusing on what is left by logging rather than how much volume is taken (Swanson and Franklin 1992; Franklin 1993; Franklin *et al.* 1997; Hansen *et al.* 1991, 1993; Perry 1995); as clear a statement as I have seen on this issue was by a Montana logger, quoted in a recent National Geographic article, who said "a logger needs to know when to quit."

We have learned the importance of critically examining dogma. For at least the past 40 years, forestry schools have taught and foresters have practised a single-minded way of doing things, and much of forestry science worked within that framework. The whole system reinforced itself and in many minds became *THE WAY*. However, as early foresters well knew, there are in fact many ways to do things (a tradition of diversity kept alive in the modern era by a few rebels). Dogmas that have fallen in the coastal Douglas-fir region include "clearcutting is necessary to regenerate" (it is not) and "long rotations are not economically viable" (they are). A few landowners have used single tree or group selection successfully for decades (Oregon State University hosted a conference on selection silviculture in Spring, 1997). Long rotations are being promoted by some of the region's leading silviculturists and wildlife biologists (e.g., Curtis and Marshall 1993; Curtis and Carey 1996). Douglas-fir maintains good growth to a ripe old age and, if stands are periodically thinned, mean annual increment (MAI) doesn't culminate until well past 150 years of age (Newton and Cole 1987). Long rotations greatly increase options for producing structurally diverse stands and landscapes, thereby significantly enhancing diversity of managed forests (Newton and Cole 1987; Perry 1994, 1995; Curtis and Carey 1996).

Maintaining native diversity is a fundamental principle that applies to all forest types. The aesthetic, spiritual, and recreational value of diversity is real and important to society, and the importance of diversity in sustaining ecological integrity (including productivity) is undeniable (Brown and Ewel 1988; Ewel *et al.* 1991; Perry *et al.* 1989; Frank and McNaughton 1991; Tilman 1996; Tilman *et al.* 1996; Tilman and Downing 1994; Naeem *et al.* 1995; Perry and Amaranthus 1997), though the situation is more complicated than simply saying diversity equals stability (a statement that has invoked much debate among ecologists over the years). Ecosystem integrity—defined by Angermier and Karr (1994) as "a system's wholeness, including presence of all appropriate elements and occurrence of all processes at appropriate rates"— emerges from linkages between ecological structures and processes spanning scales from microscopic to global (Perry and Amaranthus 1997). Some of these linkages are reasonably well understood, some not, invoking Aldo Leopold's first rule of intelligent tinkering, to save all the pieces.

Ludwig *et al.* (1993) urge acknowledging uncertainty and distrusting claims of sustainability, advice I agree with wholeheartedly. Once the reality of "certain uncertainty" is confronted, the need for maintaining flexibility becomes obvious, as does the wisdom of protecting those structures and processes through which natural ecosystems maintain integrity (Perry and Amaranthus 1997). The term sustainability is often used much too loosely, without addressing exactly what is to be sustained, how it will be done, and how performance will be monitored and evaluated (Ludwig *et al.* 1993). The most important first step in achieving sustainability is to clearly identify what society wants to sustain, what legacies people want to leave the future. Once goals are clearly identified, the trade-offs and information necessary to achieve those goals follow.

Though better understanding of societal goals and the technical means of achieving them are vitally important, experience has taught us in the Pacific Northwest that institutional inertia can be the most formidable obstacle to change. It is in the nature of institutions to filter information, accepting that which supports and discounting, rejecting, or just ignoring that which threatens the status quo (see Bella 1997 for an insightful analysis).

To avoid the traps inherent in such behaviour requires a decision-making process fully open to public and scientific scrutiny. It should go without saying that being open means being responsible to legitimate concerns. Land management agencies in the US went through an unfortunate period of patronizing the public, pretending to listen, then going ahead to do whatever they (the agencies) wanted, an approach that only angered people and fuelled distrust. (And invoked former Forest Service Chief Jack Thomas' directive to "obey the law, tell the truth").

Perhaps the most important lesson for forestry from the past decade in the Douglas-fir region is the world has changed. The fact that forests have important values other than wood fibre is widely recognized by societies throughout the world, something that is unlikely to change. One consequence is that the creation of a new role for resource professionals, that of providing conceptual leadership, which Peter Senge (author of The Fifth Discipline) defines as "*. . .* the ability to lay out difficult issues in a balanced and clear way. The simple goal *. . .* is to elevate the quality of thinking and the quality of discourse" (quoted in USA Today, August 26, 1996).

In many ways we're still on the steep part of the learning curve in the Pacific Northwest; however, most everyone agrees on the importance of communicating clearly and honestly, empathizing rather than demonizing, clarifying long-term goals, acknowledging that "de nile" is not a river in Egypt, listening to and learning from one another and, most importantly, listening to and learning from nature.

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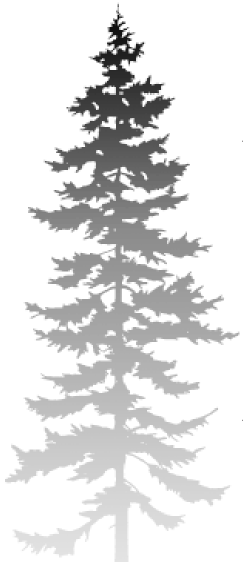

DOUGLAS-FIR MANAGEMENT IN THE INTERIOR NORTH WESTERN UNITED STATES

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Douglas-fir is one of the most wide ranging conifers of the Inland Western United States. It occupies some of the most majestic country of the Rocky Mountains. It grows in wide ranging environments throughout its range. In general it occurs at higher elevations in the southern Rocky Mountains compared to the lower elevations where it is found in the northern Rocky Mountains. Many of these environments are not that dissimilar to those found in central British Columbia.

Temperature and Precipitation Ranges Where Douglas-fir grows

Rocky Mt. Region	July C	January C	Precip. mm	Snow cm
Northern	14 to 20	-7 to 3	560 to 1020	40 to 580
Central	14 to 21	-9 to –6	360 to 610	50 to 460
Southern	7 to 11	0 to 2	410 to 760	180 to 300

Elevations (m) where Douglas-fir grows

Rocky Mountain Region	Mean	Low	High
Northern	1097	427	2377
	1463	610	2591
	2408	1829	2926
Southern	1890	1615	2195
	2621	1768	3231
	2530	2134	3353
	2469	1524	3048

POTENTIAL VEGETATION TYPES CONTAINING DOUGLAS-FIR

- Douglas-fir (climax)
- Grand fir (seral)
- Western redcedar (seral)
- Western hemlock (seral)
- Subalpine fir (seral)

Douglas-fir grows in primarily four different potential vegetation types (habitat types). It is climax in one series and seral in the others. Most often, it grows in mixed stands along with a variety of other conifers including ponderosa pine, western larch, western white pine, and lodgepole pine to name a few. The potential vegetation classes developed in the western US have similar biogeoclimatic zones defined in British Columbia. The ones listed here are used in the Nelson area of British Columbia. Similar correlations could be developed for central British Columbia. By doing so, the information developed for habitat types in the U.S. could be more readily applied in B.C.

Biogeoclimatic/Potential Vegetation Correlations

Bio-subzone	Site Assoc.	Pot. Veg.
IDFmw1	FD-Feathermoss	PSME/PHMA
ICHdw	CwHw-Falsebox	TSHE/CLUN
ICHmw2	HwCw-Falsebox	TSHE/CLUN
ICHmk1		ABLA/LIBO
ESSFdk	SxBIPa-False azalea	ABLA/MEFE

Biogeoclimatic/Potential Vegetation Correlations

Bio-subzone	Site Assoc.	Pot. Veg.
Ppxhi	FdPy-P.grass	PSME/CARU
IDFxh1	Py-P.grass	PSME/AGSP
IDFxh1	FdPy-P.grass	PSME/CARU
IDFxh2	Fd-Feathermoss	PSME/CARU
IDF-dmi	FDPI-Twinflr	PSME/LIBO

DOUGLAS-FIR MANAGEMENT

To meet management objectives:

— Timber production
— Wildlife habitat
— Water yield
— Aesthetics
— Spiritual
— Forage production

The means to meet management objectives

— SILVICULTURE

SILVICULTURAL SYSTEMS

Planned series of treatments through the life of a stand

Even-aged systems

— Seed tree
— Shelterwood
— Clearcut

Uneven-aged systems

— Group selection
— Individual tree selection

Forests in the inland northwestern US are being managed for ever increasing objectives. Traditionally timber production was the primary forest use. Now, water, wildlife, aesthetics, and even spiritual objectives are being developed for managing Douglas-fir forests. And the means to meet all of these objectives is through the practice of silviculture. Silviculture is applied by developing silviculture prescriptions using silviculture systems. Douglas-fir can be managed using both even-aged and uneven-aged silviculture systems depending on the site and management objectives. The first stage in the life of a forest is the germination, regeneration, and development of vegetation which is highly influenced by site preparation.

SITE PREPARATION

- Smith 1962 - Practice of silviculture
- Soil treatments
- Vegetation treatments

The reduction of competing vegetation, the removal of physical obstacles, and drainage of water towards or away from seeding or planting sites.

ECOSYSTEM CONNECTIONS

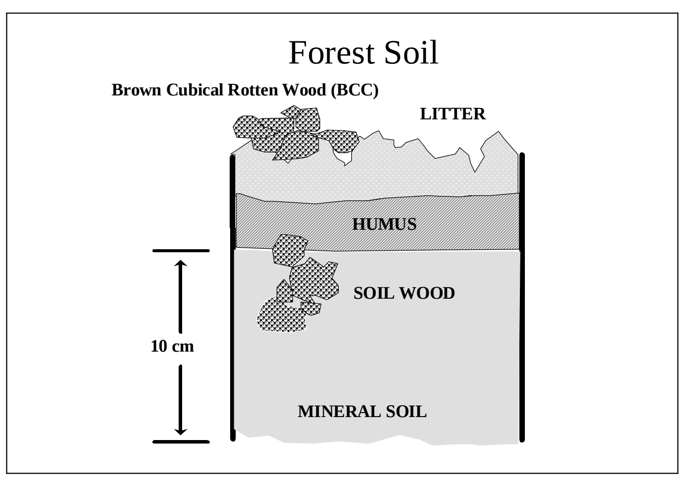
The degree of integration between biotic components of an ecosystem is such that relatively diminutive components often play a key role in the functioning of the entire system. The role minor vegetation in forest ecosystems is an example.

Ectomycorrhizae- - - goshawk
Blister rust- - - grizzly bear

SOIL

The foundation of ecosystems. It must be protected if forests are going to be sustained and is even more critical when the threats of global climate change and increased acid deposition are contemplated.

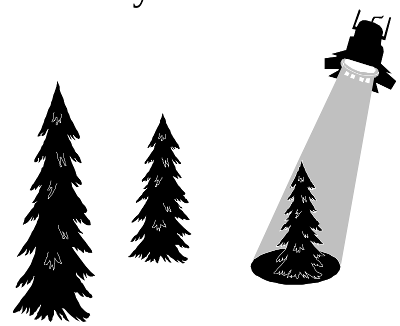
The more we learn about forest ecosystems the more we do not understand. Often components within ecosystems are intricately connected in ways that can not be readily described. For example, ectomycorrhizae (root borne fungi) are important for tree growth. Also, their fruiting bodies provide food for small rodents, which in turn supply food for a top level predator like the goshawk. White pine blister rust is killing white bark pine which in some forest types supply large amounts of pine nuts an important food for grizzly bears. Sometimes these types of connections and components of ecosystems are often overlooked. Which is sometimes the case for forest soils. A component of forest soils which is often overlooked or ignored is the organic component. These components range from buried rotten wood (soil wood) to crumbly rotten wood (BCC) on the surface.



FOREST SOILS

- Litter: Consists of fresh leaves, twigs, rotten wood, and other debris
- Fermentation: Organic layer beneath the litter layer
- Humus: Layer of unrecognizable plant parts
- Soil wood: Buried BCC
- Surface mineral: 0 - 10 cm
- Deep mineral: 10+ cm

Most limiting nutrient in the Rocky Mountains?



The surface layers of forest soils are rich in organic matter. In some forest types these layers can be quiet deep (cedar/hemlock) and in others the organic layers are shallow (ponderosa pine). These materials store and cycle nutrients and physically protect mineral layers from erosion. Forest growth in the Rocky Mountains is most limited by nitrogen (N). This nutrient can only become available to plants through fixation. Non-symbiotic fixation occurs when free living bacteria change atmospheric N to a form plants can use. Like wise, symbiotic fixation occurs when nodules on the roots of certain plants (alder, ceanothus, lupine etc.) complete the same process. Because N is so important and only becomes available through fixation its conservation is important. Forest soil organic components and the surface mineral soil can contain up to 56 percent of the N in a forest soil.

NITROGEN-FIXATION

- Non-symbiotic
- Symbiotic

Nitrogen Contents
Douglas-fir/Ninebark Pot. Veg. Type

Component	Amount kg/ha/N	Percent
CWD	68	3
Soil Wood	419	16
Forest Floor	438	17
Mineral 0-5 cm	543	21
*Percent	Vulnerable	56
Min. 10-30 cm	1162	44

- *Subject to displacement and volatilization from harvesting and site preparation

ECTOMYCORRHIZAE

- Water uptake
- Nutrient absorption
- Fruiting bodies
- Food for small animals
- Strong association with organic materials
- **<u>BIO INDICATOR</u>**

ECTOMYCORRHIZAE DISTRIBUTION

Component	Percent
Litter	14
Soil wood	33
Humus	30
*Vulnerable	77+
Mineral soil	23

*Subject to displacement and volatilization from harvesting and site preparation

In addition to N, ectomycorrhizae are an important component of forest ecosystems often overlooked. They play an important role in providing nutrients and water to forest vegetation. Also, because of their strong relationship with organic materials they make an excellent bio-indicator of healthy forest soils. Similar to N, up to 77 percent of the ectomycorrhizae activity in a forest soil can occur in the organic components. These components are highly susceptible to disturbance and destruction by forest management activities and wildfire.

IMPORTANCE OF ORGANIC MATTER-LITTER

- Physically protects soil
  - — Compaction
  - — Erosion
- Maintains soil moisture
- Stores and releases nutrients-N,P,Ca,Mg,K
- Provides OM for lower layers
- Site for ectomycorrhizae formation

IMPORTANCE OF ORGANIC MATTER-HUMUS

- Physically protects soil
- Active rooting zone
- Nitrogen fixation (10-15%)
- Nitrogen storage (15-35%)
- Stores moisture
- Stores and releases nutrients-N,P,Ca,Mg,K
- Site for ectomycorrhizae (30-70%)

IMPORTANCE OF ORGANIC MATTER-SOIL WOOD

- Active rooting zone
- Nitrogen fixation (10-15%)
- Nitrogen storage (15-20%)
- Stores moisture
- Stores and releases nutrients-N,P,Ca,Mg,K
- Site for ectomycorrhizae (10-50%)

The organic components (litter, humus, soil wood-buried rotten wood, residue) play important roles in forest ecosystems. These materials protect the mineral soil from erosion as well as protect new forest growth (seedlings) from animal, mechanical, and weather related damages. All of these materials are important source of nutrients and nitrogen fixation especially the humus and soil wood components. Similarly, these materials are important sites for mycorrhizae formation as is the surface mineral soil.

IMPORTANCE OF ORGANIC MATTER-SURFACE MINERAL

- Active rooting zone
- Nitrogen fixation (10-15%)
- Nitrogen storage (10-25%)
- Stores moisture
- Stores and releases nutrients-N,P,Ca,Mg,K
- Site for ectomycorrhizae (5-15%)

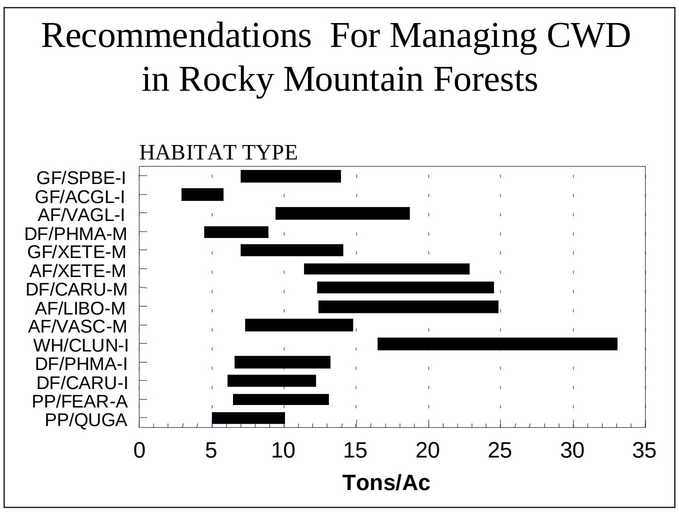
IMPORTANCE OF ORGANIC MATTER-RESIDUE

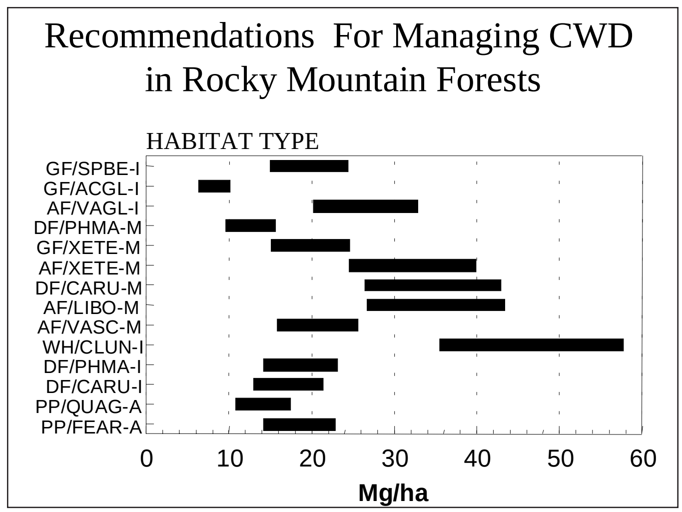
- Protects seedling from abiotic and biotic damage
- Nitrogen fixation (0.3 to 1.7 kg/ha/yr)
- Provides OM

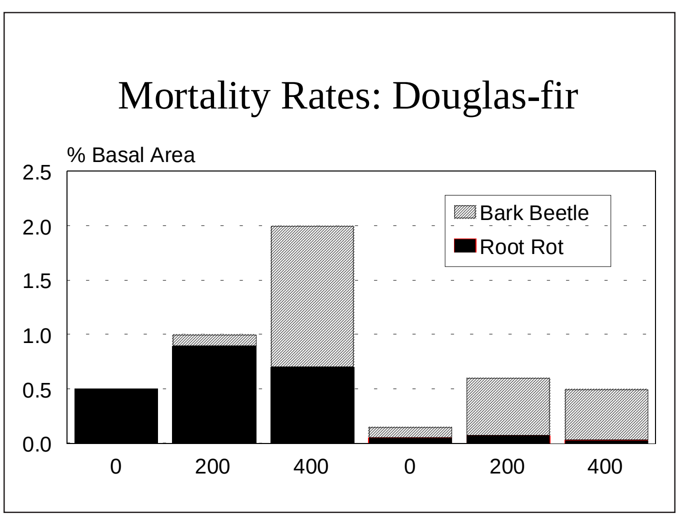
FOREST RESIDUE

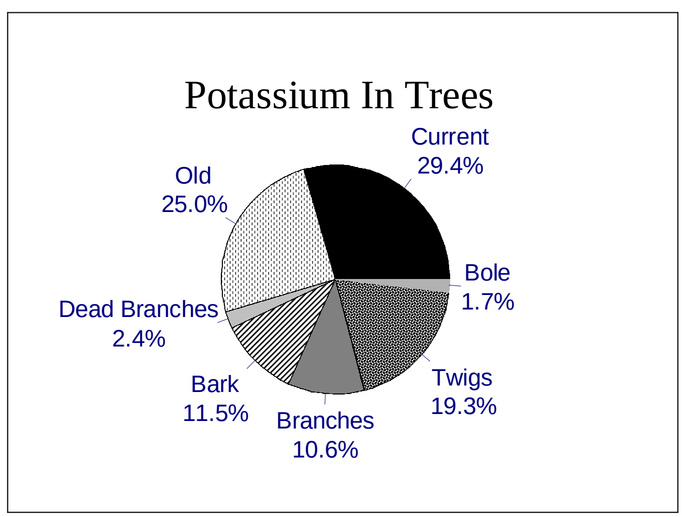
- New: Recent dead logs and branches
- Incipient: Decay process starting
- Intermediate: Large amounts of soft wood, some brown cubical rotten wood (BCC)
- Advanced: Mostly BCC

Forest residue (limbs and boles) in various stages of decay play many roles in maintaining forest productivity in addition to providing habitat for a wide variety of wildlife species. Various amounts of course woody debris (CWD) occurs naturally in forest ecosystems. However, through timber harvest and fires large amounts of this material is removed. In managing forests for timber production CWD becomes an important source of organic matter. Therefore, depending on potential vegetation type various loadings of CWD are recommended for maintaining forest productivity. They range from 7 Mg/Ha (metric tons) on a grand fir type to 74 Mg/Ha in a western hemlock type (See Graham and others 1994).

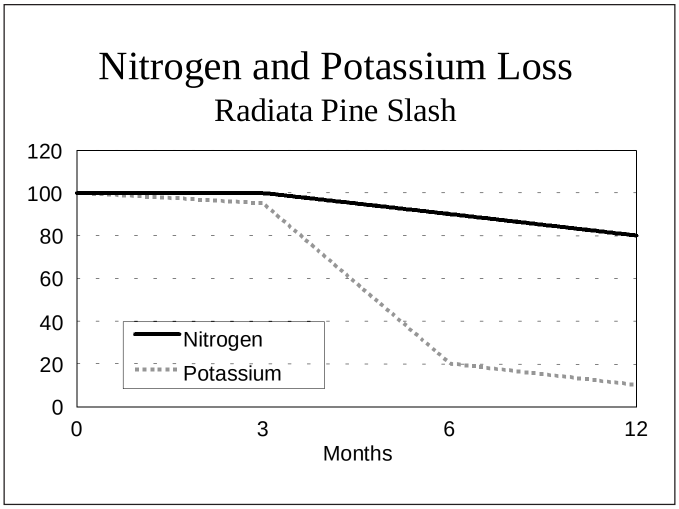


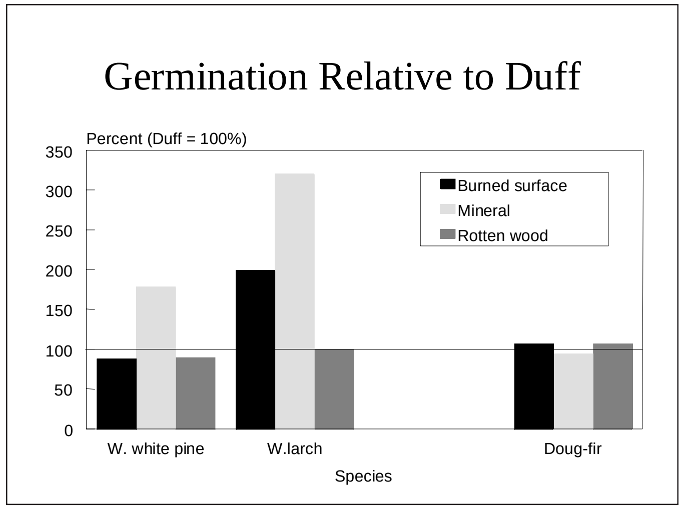


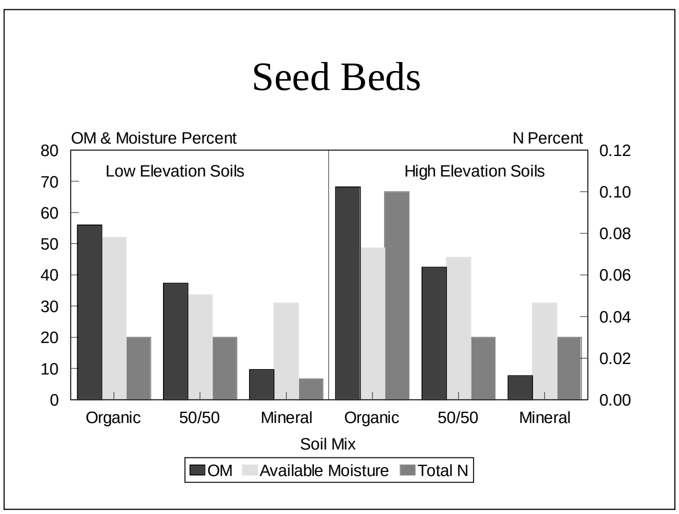


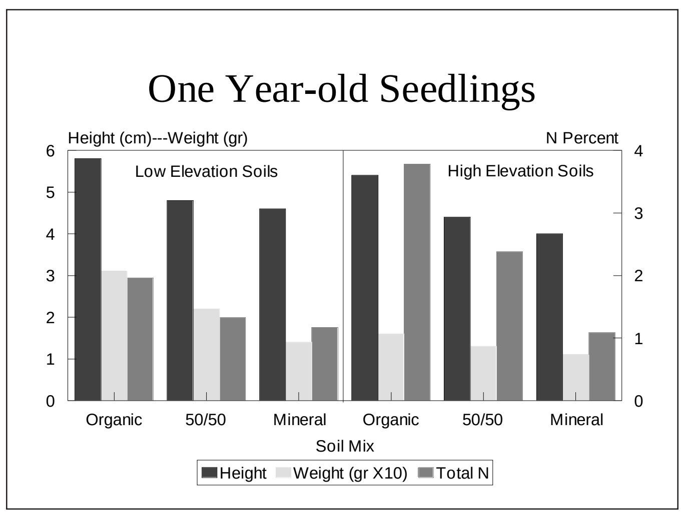


Nitrogen is an important nutrient for forest development but other elements are also critical. Potassium (K) primarily occurs in the foliage and branches of trees. In contrast to N, K becomes available through the weathering of rocks--a very long process. Re cently the nutrition coop at the University of Idaho has demonstrated a relationship of mortality in Douglas-fir to foliar K levels. Tre es with poor foliar K had higher mortality than trees with good foliar K regardless of the N fertilization level. Because of this relations hip, practices that remove (whole tree harvesting) or concentrate tree tops (slash piling) have the potential of removing K from the forest. Possibly making trees more susceptible to attack by insects and diseases. If slash is allowed to remain in place over winter much of the K is leached from the foliage and would remain on the site even if the slash was removed, burned, or piled.

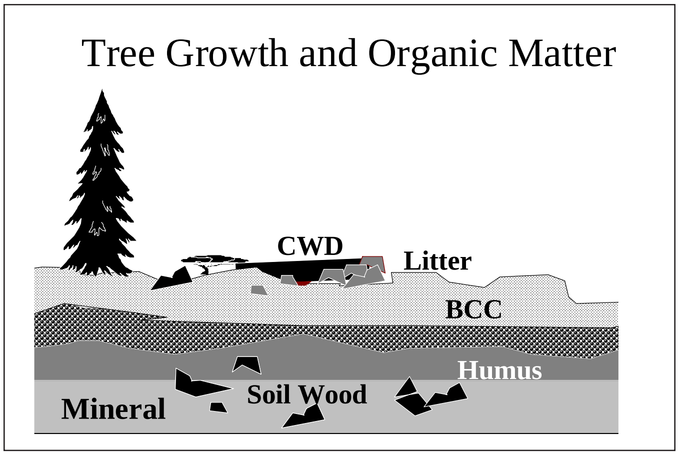


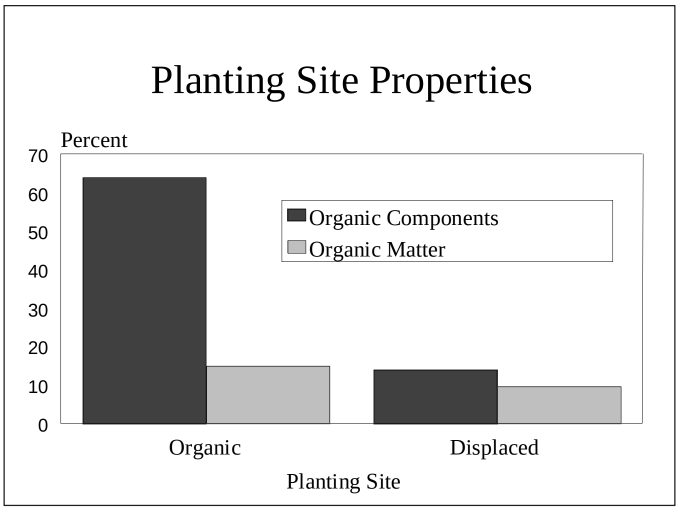


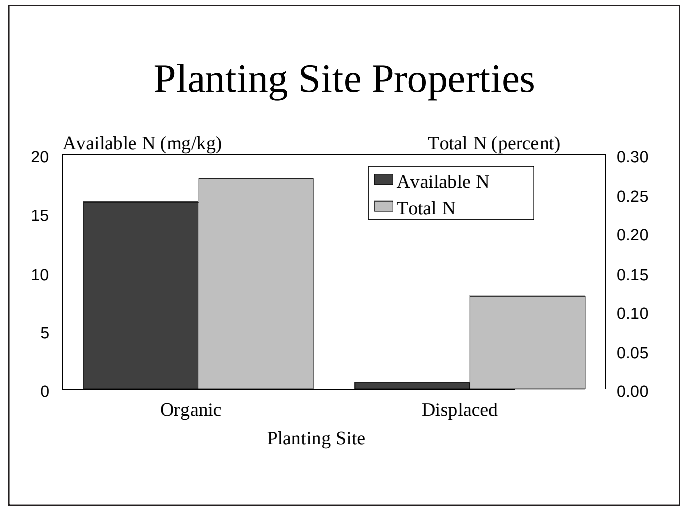




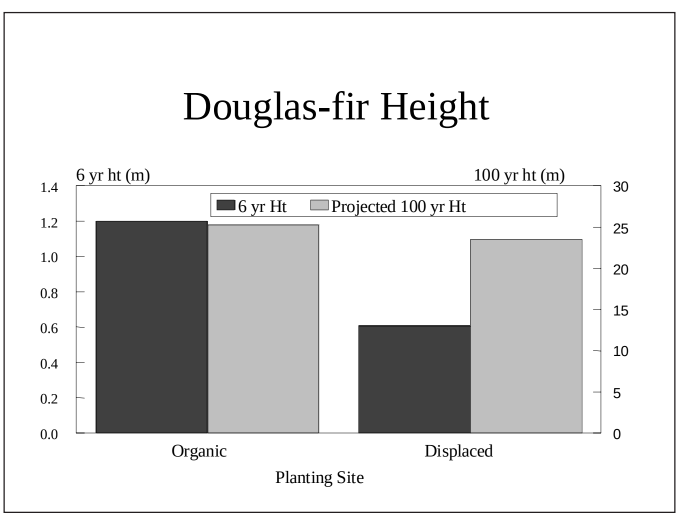
Douglas-fir, germinates uniformly no matter the substrate. Duff, burned surfaces, mineral soil, and rotten wood all appear to result in similar germination (slide 36). Seed beds rich in organic matter contain more moisture and N than seed beds of mineral soil. This appears to be the case for soils occurring at high (800 m) or low (600 m) elevations. Seedlings growing in soils rich in organic matter at one year were taller, heavier, and had higher N concentrations then seedlings growing in mineral soil. Organic matter is important for the growth of newly established seedlings.

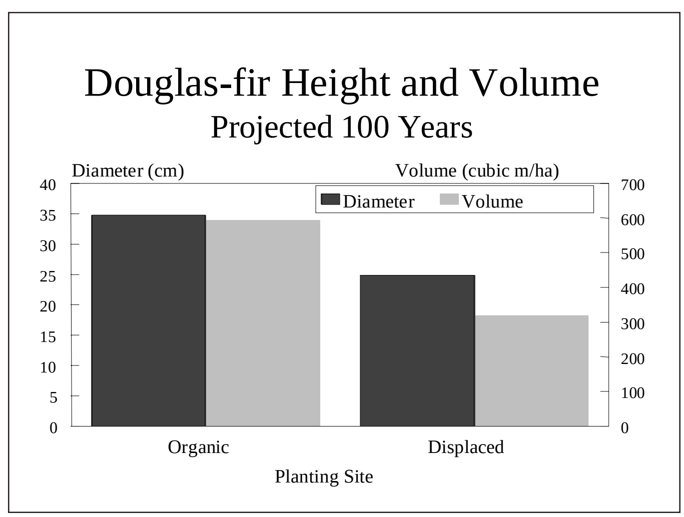


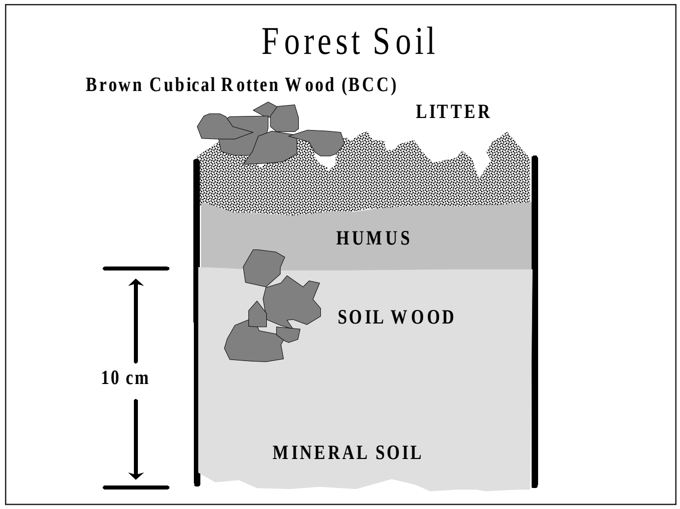




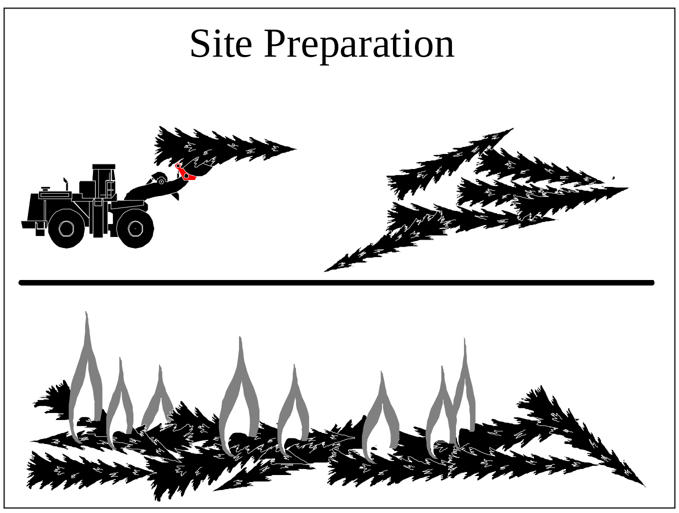
Planted Douglas-fir also respond to soils rich in organic matter. When planting sites are enriched with organic matter by mounding both available and total N is increased. Douglas-fir planted in these organic matter rich soils were taller at 6 years compared to trees growing in soils in which the organic matter was displaced. A similar trend was observed when growth models were used to predict height at 100 years. Similarly, predicted diameters and volumes per hectare were also much greater for Douglas-fir planted in organic rich soils compared to trees planted in mineral soils.







Therefore, forest soils, an important forest component, are often over looked, abused, and misused. In particular the organic component, brown cubical rot (BCC), litter, humus, and soil wood (buried brown cubical rot), are often displaced, removed, or destroyed during forest management operations. These materials are rich in nutrients and excellent sites for supporting ectomycorrhizae formation. Often these materials are manipulated during site preparation to enhance, ensure, or encourage natural or artificial regeneration.



SITE PREPARATION OBJECTIVES

- Control competing ground-level vegetation
- Add new vegetation to control erosion or inhibit interfering plants
- Remove or mix the litter and upper mineral soil horizons
- Promote decomposition of the surface litter
- Expose mineral soil
- Alter the habitat for damaging agents
- Enhance conditions for wildlife
- Reduce fuels
- Reduce impediments to human activities

FACTORS INFLUENCING PLANT GROWTH

- Water
- Heat
- Light
- Nutrition
- Damage

SITE PREPARATION

- Mechanical
  - —Hand, machine
  - —Scalp vs. clearing
- Fire
  - —Duration and intensity determine what is left
- Chemical

In preparing site preparation prescriptions, often the factors that influence plant growth are ignored. Whether mechanical methods, fire, or chemicals are used to prepare sites for natural or artificial regeneration the factors that control plant growth should be enhanced and maintained. Because organic materials are important I recommend that planting spots be cleared of debris but not necessarily scalped to mineral soil. Scalp to remove competing vegetation but not to plant in mineral soil. However, ensure that seedling roots have good contact with the soil.

MACHINE

- Tractor piling
  - Distribute CWD across harvest sites
  - Separate fine materials from CWD
  - Can compact and displace soils
  - Limited by slope
- Grapple piling
  - Separate fuels
  - Work on steep slopes
  - Minimize soil disturbance

MACHINE

- Roller chopping and chipping
  - Create deep compacted layers
- Insulating the soil surface
- Slowing decomposition
- Especially on cool and cold sites
  - Destroys
- Nitrogen fixation
- Animal habitat
- Site protection

PRESCRIBED FIRE

- Does not concentrate fine fuels
- Removes primarily hazard fuels
- Under proper conditions (High lower duff moisture)
  - Can maintain forest floor
  - Capture nutrients released during burning
- Charring does not appreciably interfere with decomposition or function of CWD
- Greatest limitation
  - Smoke emissions

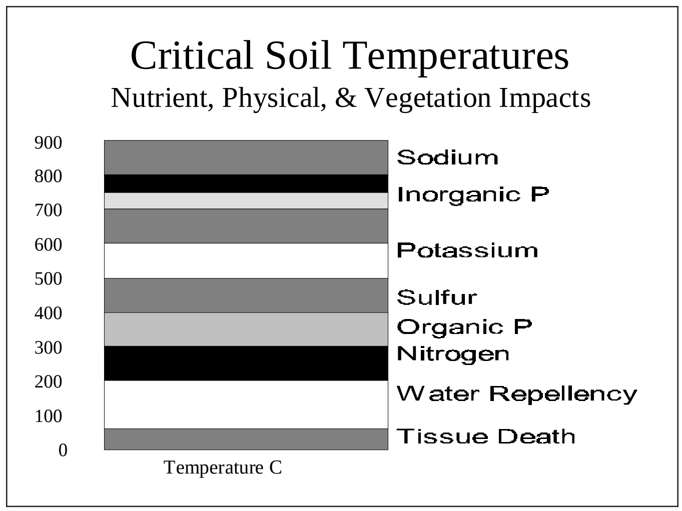
Machine piling of logging debris and preparing sites for regeneration can be accomplished by both tractors and grapple machines. Grapple machines have greater flexibility for separating fuels and distributing CWD compared to crawler tractors. They can work on steeper slopes than tractors and tend to cause less soil disturbance and compaction. Roller chopping or chipping of slash cancreate deep compacted layers potentially insulating the soil surface especially on cold sites creating permafrost-like conditions. Also, these kinds of activities destroys the N-fixing capability of CWD and minimizes its effectiveness for protecting the site and providing animal habitat.

FIRE EFFECTS

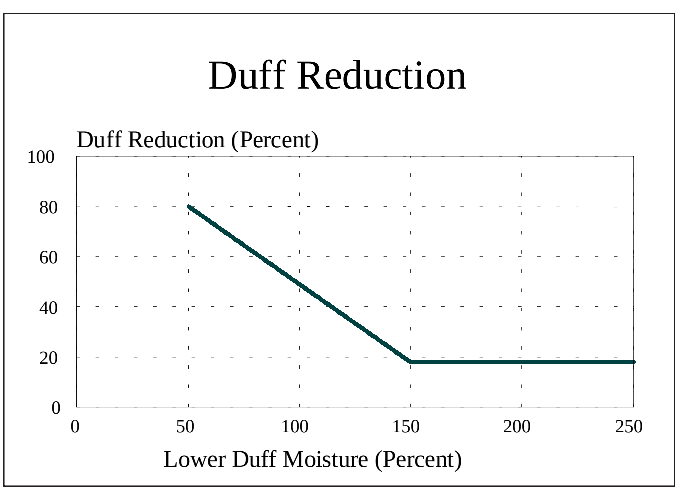
•Residues
— Consumes all ‹ 3"
— Consumes portion of › 3"
•Litter
— Nearly total consumption
•Humus
— Consumption depends on moisture
— Moisture › 100% consumption minimal

FIRE EFFECTS

•Soil wood
— Buried
— High moisture content
— Consumption minimal
— Long duration fires can consume
•Mineral soil
— OM volatilization
• Hydrophobic soils
•Erosion, nutrient loss
— Increase in soil bulk density
— Organic matter loss



Prescribed fire is an excellent tool for preparing for regeneration and decreasing fire hazard. It does not concentrate fuels which could impair K relationships and if done properly CWD and much of the forest floor can be maintained. Nutrients can be released and if lower duff moistures exceed 100% during the burn some nutrients can condense in the humus and upper mineral soil. The biggest limitation to the use of prescribed fire is the production of smoke. Fire can damage soils and cause the loss of nutrients especially if temperatures at the interface between the organics and the mineral soil exceed 300 degrees C. Potassium does not volatilize until temperatures exceed 600 degrees C, an extemely hot fire.



IMPORTANT POINTS

•Develop prescribed fire prescriptions to maintain organic matter (humus % soil wood)
— Burn when lower duff (humus) moisture 100%+
•Minimize soil compaction & displacement
— Organic layers ameliorate compaction
— Scalp and scarify for a purpose
— Use prescribed fire
— Use grapple piling
— Use tractor piling sparingly

DISTRIBUTE AND PROVIDE COARSE WOODY DEBRIS

- Provide coarse woody debris in prescribed amounts
- Distribute across harvest sites
- Concentrations minimized using:
  — Whole tree harvesting
  — Machine piles

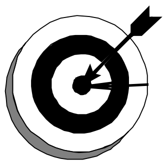
COARSE WOODY DEBRIS RECOMMENDATIONS

- Leaving CWD can not ameliorate poor harvesting or poor site preparation
  — Depending on decomposition rates it may take hundreds of years for CWD to be incorporated into the mineral soil
- RECOMMENDATIONS ARE NOT INTENDED TO REPLACE THE PRESENT FOREST FLOOR
  — CWD left after harvesting is for the development and function of the next forest as the present

No matter the site preparation and fuels treatment prescribed they should ensure the maintenance of CWD. The management of CWD is a long-term proposition. Maintaining CWD does not ameliorate poor site preparation or harvesting practices. Vegetation management and site preparation need to be integrated in to a silviculture system, not a separate item. Artificial regeneration is common for Douglas-fir but important precautions should be observed.

MOST IMPORTANT

INTEGRATE ALL ASPECTS OF VEGETATION MANAGEMENT AND SITE PREPARATION INTO THE SILVICULTURAL SYSTEM!!!



ARTIFICIAL REGENERATION

- Seed zones
- Bare root
- Container
- Season of planting

PLANTING DOUGLAS-FIR

- Container
  — Dormant summer plantings possible
  — Fall planting used
  — Preferred for high organic soils
- Bare root
  — Spring
  — Larger seedlings
- Small seed zones
  — Douglas-fir is a specialist

Evolutionary Mode

Elevation width and frost free days of seed zones

Species	Elevation m	Frost-free days	Mode
Doug-fir	200	18	Specialist
L. Pole	220	20	Specialist
E. Spruce	370	33	Intermediate
P. Pine	420	38	Intermediate
Red Cedar	600	54	Generalist
White Pine	None	90	Generalist

Both bare-root and container stock are used in planting of Douglas-fir. Container stock can be used in any season and currently dormant summer plantings are starting to be used. Bare-root seedlings are well suited for sites that require large seedlings. Container stock are well suited for planting sites rich in organic matter in which root to soil contact during the planting process may be difficult. Compared to its associates Douglas-fir is the most specialized, the exact opposite of western white pine. With these traits in mind managing sites in the presence of *Armillaria* the preferred approach is species management. On sites (often droughty with shallow soils) where *Armillaria* is a problem, species (western white pine, ponderosa pine, western larch) other than Douglas-fir are preferred.

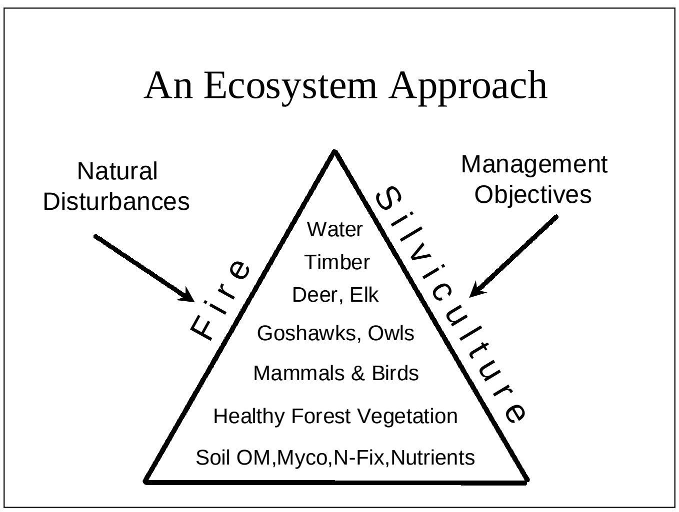
ARMILLARIA MANAGEMENT

- Species preference (these species are resistant)
  - Western white pine
  - Ponderosa pine
  - Western larch
  - Lodgepole pine
- Healthy soil
  - Organic matter rich
  - Good physical structure
- Proper seed source

INDICATORS OF HEALTHY, PRODUCTIVE FORESTS

- Organic matter rich soil
- Adequate organic reserves
- Microbiological activities
  - Ectomycorrhizae
  - Nitrogen fixation
  - Carbon/nitrogen cycles

Ecosystems, silviculture, organic matter all are not new concepts or ideas. How they are used to address the problems facing forest management during the 21st century is the challenge. Forest health or ecosystem health is necessary for our species and all the others that occupy the earth to survive. Excellent indicators of forest health are organic matter rich soil, organic reserves (CWD), and microbiological activities. If these ecosystem components are present and functioning it is difficult not to have healthy forest vegetation, good populations of wildlife, and abundant timber and water.



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DOUGLAS-FIR IN THE BRITISH COLUMBIA INTERIOR:
RESEARCH AND MANAGEMENT EXPERIENCE

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MANAGEMENT OF UNEVEN-AGED STANDS IN THE CARIBOO FOREST REGION

Throughout the Interior Douglas-fir (IDF) biogeoclimatic zone in the interior of British Columbia, management of uneven-aged Douglas-fir stands has had a varied past, and management of these stands in the Cariboo Forest Region has been no exception. Prior to the mid to late 1960s, stands were managed on a mark-to-cut or mark-to-leave system. This intensive system of marking employed large marking crews and was both costly and difficult to administer. For these reasons, a diameter limit cut was adopted.

The diameter limit cut was easier and more economical to employ as marking was no longer necessary. Minimum diameters were generally set at 30 to 40 cm with the objective being to remove as much volume as possible without devastating the stand. Perhaps, depending upon the amount of logging disturbance, some sites regenerated abundantly to Douglas-fir, but the variability in regeneration success and the notable failure to re-establish Douglas-fir on many sites hailed a return to a selection system in the mid 1980s (G. Chapman, pers. comm.) The idea behind this change in management was that the residual stand would provide a seed source as well as shade for establishing regeneration.

In stands currently managed by single tree selection, volume is harvested from the range of diameter classes in the stand. The concept of managing to a reverse 'j' diameter distribution is utilized and generally 50 to 60% of the volume is harvested (this often equates to approximately 50% of the basal area). Three to four cutting rules are developed for simplification of the selection process.

Mule deer at their northern limit use interior Douglas-fir forests as winter range. Winter range represents about 250,000 hectares or 15% of the Douglas-fir forests in the Cariboo Forest Region. Guidelines for harvesting on winter ranges, where uneven-aged stands are present were developed in 1986 (Armleder *et al.* 1986). Low volume (15 to 20%) single tree selection/group selection (groups of up to six trees) can combine timber extraction with habitat maintenance. On winter ranges, harvesting is concentrated in the gullies and on north-facing slopes, aspects not used as frequently by the deer as are the ridges and the south-facing slopes.

The IDF zone in the Cariboo Forest Region is dominated by two dry, cool subzones: IDFdk3 and IDFdk4. Where poor logging practices or wildfires have created unstocked openings in these subzones, attempts to regenerate Douglas-fir have been largely unsuccessful. Openings typically experience summer droughts and damaging frosts can occur at any time over the summer. Since Douglas-fir is the least frost-tolerant coniferous species in the Cariboo Forest Region, it is particularly susceptible to damage. Typically, these backlog openings in the IDF are site-prepared and planted to lodgepole pine, based on management experience and research results.

Site preparation trials were established in the IDFdk3 and dk4 in 1985 and 1988 on grassy, frost-prone sites to determine if mechanical site preparation had potential to reduce the impact of summer frost on Douglas-fir seedlings. On one site, survival was $<$ 20% regardless of site preparation with frost being the limiting factor. Survival on the other two sites was generally $>$ 50% when seedlings were planted in continuous site preparation: ripping, disc trenching or v-plow site preparation[1] (Daintith and Newsome 1996).

Growth of Douglas-fir on these trials has been variable, depending on the degree of frost damage which is often microsite specific. The IDFdk4 subzone contains the most frost-prone sites where Douglas-fir forests are common. Consequently, many seedlings are damaged yearly by frost and this has a significant impact on growth and form. Similar to survival, growth is generally improved with continuous site preparation as the grass canopy is removed along with surface organic layers, reducing competition and increasing soil moisture and warming. On some sites, however, even intensive site preparation cannot alleviate the severity of frosts and planting Douglas-fir is not a viable option.

MANAGEMENT OF EVEN-AGED STANDS IN THE CARIBOO FOREST REGION

Where the IDF grades into the surrounding dry warm Sub-Boreal Spruce subzones (SBSdw1 and SBSdw2), the risk of frost

1 Konowalyk, L. 1995. Site preparation options for improving plantation performance in low precipitation areas of the Cariboo Forest Region. BC Min. For., Williams Lake, BC Unpubl. Rep.

is reduced due to generally higher atmospheric humidity and cloud cover (Steen *et al.* 1990). On these sites and in the ICH (Interior Cedar-Hemlock) Zone, Douglas-fir is a productive, long-lived seral species and is found in even-aged stands often in combination with either lodgepole pine or interior spruce.

Stands are typically clearcut and planted although the major limitation to using Douglas-fir for regeneration is its susceptibility to frost. Therefore, its use is limited to low frost-hazard sites: generally upslope areas of mid-slopes greater than 15% (Steen *et al.* 1990). Even on these low frost-hazard sites, Douglas-fir will occasionally suffer damage and isolated mortality.

Research on site preparation and plantation establishment on dry, warm SBS sites was conducted simultaneously with the research in the IDF. On these sites, survival and growth of Douglas-fir was significantly improved over that achieved in the IDFdk subzones. Recommendations based on five- and ten year results include using some type of continuous site preparation and planting Douglas-fir in a mixture with other species (Daintith and Newsome 1996).

Managers are reluctant to plant pure Douglas-fir on these sites and it is generally planted as a mixture with lodgepole pine on the drier sites and interior spruce on the wetter sites (G. White, pers. comm.) A common prescription on SBSdw1 and ICHmk3 sites is to plant 1400 stems per hectare of lodgepole pine and Douglas-fir in a 2:1 ratio (A. Vandenberg, pers. comm.) This ensures that even if all of the Douglas-fir is lost, the stand will still meet minimum stocking standards. It may be possible to increase the initial stocking and plant only Douglas-fir but this increases costs. On other sites where residual patches of timber (e.g., wildlife tree patches) have been maintained, Douglas-fir is planted where the overstorey will provide shade and protection from frost, and lodgepole pine is planted on the open ground. These management prescriptions maintain Douglas-fir in the landscape although at lower proportions than occurred in the past.

As a result of the unreliability of achieving Douglas-fir regeneration, many young, mature, even-aged Douglas-fir stands have been deferred from clearcutting in the Cariboo Region. The reason for the deferral was that young productive stands were being harvested and replaced with stands of lower value lodgepole pine (E. Johansen, pers. comm.) Maintaining Douglas-fir stands for longer periods would increase their value and perhaps allow time for regeneration issues to be resolved.

In an attempt to gain access to deferred stands and maintain Douglas-fir stands in the landscape, other silvicultural systems are being investigated which have the potential to resolve regeneration problems. Any type of overstorey greatly reduces the risk of frost as the seedlings' view of the night sky is greatly reduced. These even-aged stands are not only extremely valuable for timber but also for other resource values, such as wildlife habitat, range and aesthetics, and alternatives to clearcutting may be more suitable for maintaining these values. Consequently, a research trial was established in 1991 on three sites in the SBSdw1 to test the suitability of using a uniform shelterwood system as an alternative to clearcutting. This is a co-operative trial between Ministry of Forests, Weldwood of Canada Ltd. and the UBC Alex Fraser Research Forest.

The selected stands were Douglas-fir leading (minor amount of lodgepole pine and/or interior spruce), occurred on zonal sites, were 80-120 years old, and supported 60 m^2/ha of basal area. Two levels of basal area reduction were harvested using two harvesting methods. Thirty percent and 50% of the basal area was harvested by fellerbuncher and grapple skidder (conventional equipment) or by handfalling and small line skidder (low impact equipment). The 30% harvest was considered a preparatory cut; a seed cut is scheduled for 2001, and final cut for 2016 (three passes). The 50% harvest was considered a seed cut with the final cut scheduled for 2016 (two passes). Lodgepole pine and interior spruce were targeted for harvest before Douglas-fir and the effect of the harvesting was a 'thinning from below.'[2] While the prescriptions were for natural regeneration, treatments were underplanted two years ago in order to quantify growth response.

Climate monitoring on one of the three sites showed that damaging frosts occurred in adjacent clearcuts until late May and after mid-August. The frost-free period was approximately three to four weeks longer in the uncut and shelterwood treatments. Frost damage on seedlings planted in adjacent clearcuts, while those in the forested treatments remain undamaged, supports these findings. Relative humidity, average screen (1.3 m) and 15 cm temperatures were comparable between treatments but soil temperatures in the clearcut were far more favourable for seedling growth (17°C) compared to forested treatments (10°C).

An abundance of Douglas-fir and subalpine fir advanced regeneration was maintained on the sites but there has been very little post-harvest natural regeneration establishment. Following an excellent seed year in 1993 that produced approximately 2M seeds/ha, the number of germinants (< 2 years old) ranged from 20,000 to 60,000 seedlings/ha. Two years later, in spite of annual recruitment, the number of germinants was reduced by approximately 50% with no subsequent increase in the abundance of seedlings older than two years. Harvesting created very little ground disturbance and perhaps a lack of suitable seedbed has impeded seedling establishment. Germination and survival studies on different seedbeds on one of the shelterwood sites show that moss (a common substrate) is a universally poor seedbed (10% germination) while exposed decayed wood is the most superior (45% germination) followed by mineral soil.[3]

2 Daintith, N. 1993. Uniform shelterwood systems for even-aged Douglas-fir/lodgepole pine stands in the SBSdw1 subzone. Establishment Rep. B.C. Min. For., Williams, Lake, B.C. Unpubl. Rep.

3 Burton, P.J. 1996. Conifer germination on different on different seedbeds influenced by partially cut canopies: summary for 1994 and 1995. B.C. Min. For., Williams Lake, B.C. Unpubl. Rep.

There have been no consistent trends in treatments between sites and years in terms of seed production and natural regeneration. Regeneration surveys indicate that all treatments on all sites are stocked although, in some cases, the mature layer must contribute to stocking in order to meet minimum stocking standards. This is a concern considering that eventually the mature layer will be harvested. Even-aged silvicultural systems, other than clearcutting, present the following operational problems:

1. Windthrow and snow breakage in the smaller stems.
2. Douglas-fir bark beetles are attracted to logging slash and windthrow. Beetle probes and salvage operations have been conducted in three of the past five years.
3. Root disease spread can potentially be increased by partial cutting. Root rot is not present on the research sites, but it is common throughout the SBS zone.

In another recently initiated co-operative trial with Weldwood, a group selection system will be tested in an even-aged Douglas-fir stand in the ICHmk3.[4] This site, which has yet to be harvested, is located on mule deer winter range. Consequently, uncut areas must remain in the stand for snow interception. Twenty percent of the stand area will be harvested using a variety of opening sizes and orientations. Openings will range from 0.25 to 2.0 ha and opening width will not exceed two tree heights (70 m). The site is located on a south-facing slope and the rectangular openings will be oriented either along or across the contour. The impact of these openings on vegetation development/forage production, natural regeneration ingress, snow accumulation, seedling growth and windthrow will be studied. An added dimension to this study is the presence of root rot; openings in the infected area will be stumped.

Douglas-fir can be successfully established on low frost hazard clearcuts but for those sites where frost is expected to be the limiting factor, these silvicultural systems appear to have potential for maintaining Douglas-fir in the landscape.

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ECOLOGY OF DOUGLAS-FIR AT ITS NORTHERN LIMITS

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Douglas-fir reaches its northern limits in regions of British Columbia that are transitional between the dry warm climatic regions of the central interior plateau, where Douglas-fir forms the dominant forest cover; and, the moist cold climatic regions of the sub-boreal plateau and boreal plains, where lodgepole pine, trembling aspen and white spruce form the dominant forest cover. Within this transitional area, Douglas-fir is most commonly found on coarser soil deposits such as eskers or colluvial deposits, or where bedrock occurs close to the soil surface. The sensitivity of Douglas-fir to frost damage is hypothesised to be the main determinant of its distribution at its northern limits. Actual data[1] from two 14,000 ha areas, one in a drier warmer biogeoclimatic unit (SBSdw3) and one in a wetter cooler unit (SBSwk1), support this hypothesis. It was found that Douglas-fir was proportionally more abundant on slopes ›20% at mid elevations (800-1000 m) than on gently sloping terrain at low elevations. Frost would tend to be more prevalent in low elevation, gently-sloping terrain due to cold air ponding. It is also a common belief that Douglas-fir prefers warmer aspects due to the longer growing season. This trend was expressed in the SBSwk1 area where Douglas-fir was proportionally more common from 180-270° and less common from 270-90° then all other species (Figure 1) . However, in the SBSdw3, other than a slight preference for exposures between 180-270°, distribution of Douglas-fir was no different from other species with respect to aspect (Figure 2).

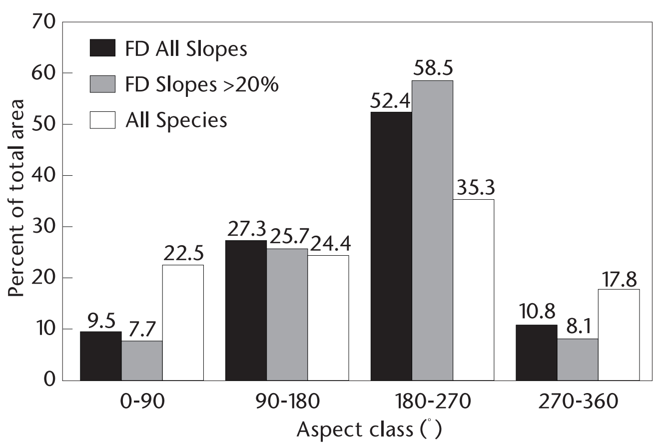


FIGURE 1. Proportion of total area of polygons dominated by (1) Douglas-fir on all slopes; (2) Douglas-fir on slopes >20%; and (3) all species on all slopes for different aspect classes for the SBSwk1 study area.

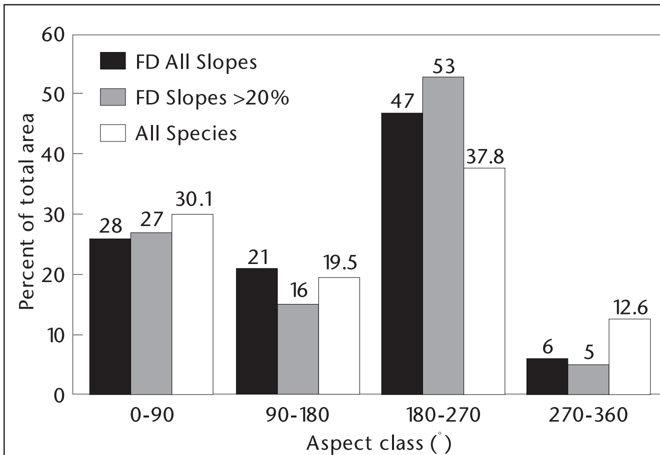


FIGURE 2. Proportion of total area of polygons dominated by (1) Douglas-fir on all slopes; (2) Douglas-fir on slopes>20%; and (3) all species on all slopes for different aspect classes for the SBSdw3 study area.

Certain species tend to occur in association with Douglas-fir indicating the same site preference or similar niche occupation. These "friends of Douglas-fir" are species such as paper birch (*Betula papyrifera*), Douglas maple (*Acer glabrum*), and Prince's pine (*Chimaphila umbellata*). Associations such as these may prove useful in identifying sites where Douglas-fir can succeed where it is not currently present.

Douglas-fir plays a unique role in the landscape at its northern limits where stand-replacement wildfire is common. As a result of its thick fire-resistant bark, Douglas-fir is selectively left in groups or as individual trees within large wildfires. These Douglas-fir are generally large and thus provide good seed sources to regenerate the burned over area, as well as providing "large

1 Delong, C. BC Ministry of Forests, Prince George Region, Unpublished data

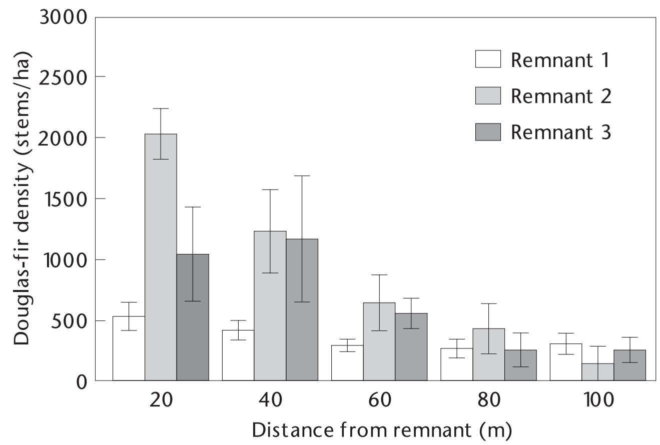


FIGURE 3. Douglas-fir density as a function of distance from the nearest mature Douglas-fir remnant left within 40-60 year old wildfires.

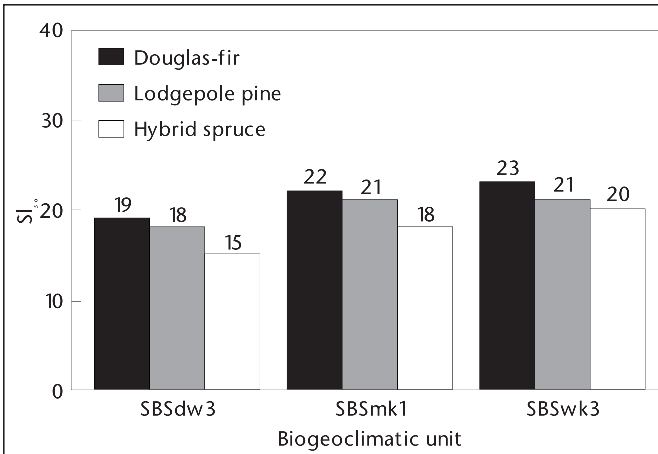


FIGURE 4. Comparison of SI_{50} for Douglas-fir, lodgepole pine and hybrid spruce on mesic sites in the SBSdw3, SBSmk1, and SBSwk3 (unpublished data from Site Index Biogeoclimatic Ecosystem Classification Correlation Project).

tree" habitat features in areas which will be dominated by small trees (i.e., <20 cm dbh) for a relatively long time (i.e., >40 years).

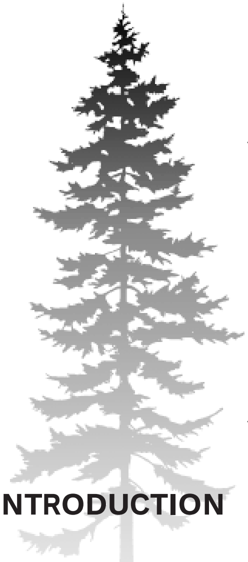
Natural regeneration is an important ecological factor to understand when attempting to retain Douglas-fir at its northern limits. This is even more critical due to some difficulties related to establishing planted stock (see papers by Beaudry, Revel and Oneil this document). A live seed source is required for Douglas-fir and data from sub-boreal forests indicate that abundant regeneration (>100 stems per hectare) can occur up to 100 m from a seed source (Figure 3). I have concluded through personal observation that the best substrates for regeneration success are well-decomposed organic matter and mineral soil. Although the most abundant regeneration often occurs on mineral soil, saplings appear to be healthier when growing on organic substrates. Successful regeneration under a canopy does occur at Douglas-fir's northern limits but only under special circumstances. It will occur on coarse-textured soils on very dry, south-facing slopes which burn more frequently than average; or, on areas that burned once heavily and then again more lightly, leaving a large number of remnant Douglas-fir. After establishment, the main ecological factors limiting success of Douglas-fir are frost, extended duration of saturated soils, moderate to deep shade, and poor nutrient supply.

Even at the limit of its range, Douglas-fir appears to be able to out-perform other species on mesic sites (Figure 4). Although it occurs less frequently on average-to-moist sites, this is where it reaches its optimum performance. On one such site where a permanent sample plot has been established, the SI_{50} of Douglas-fir was 26.2 and average dbh at 60 years was 37 cm. This site also had a relatively unique disturbance history. Based on examination of present stand composition, coarse woody debris, and the humus layer, it was concluded that the site was previously occupied by a mixed birch and willow community. After a hot wildfire, Douglas-fir established very quickly and out-competed the birch and willow over a portion of the area.

Some significant limitations of past management practices affect prospects for managing Douglas-fir in an ecologically sustainable manner. One such limitation is the reluctance to alter the species composition of a stand after harvest. In the natural system, the temporal and spatial distribution of vegetation is very dynamic and this allows for achieving optimum performance (as illustrated by the site previously discussed). Variability in intensity of disturbance, especially wildfire, is another feature of natural disturbance which has probably benefited the establishment of Douglas-fir. In contrast, a lack of variation in silviculture prescriptions and reduced amounts of broadcast burning have lead to relatively homogeneous site treatments within managed disturbances.

Based on my knowledge of the ecology of Douglas-fir, I make the following recommendations, some of which are currently being implemented in some or most jurisdictions.

- Retain variable levels of Douglas-fir, from individual dispersed trees to larger patches, within cutover areas to provide for this important ecological legacy in the managed landscape.
- Allow for increased flexibility in silvicultural obligations in order to allow for ecologically- based species conversions such as paper birch to Douglas-fir.
- Encourage innovative silvicultural prescriptions, including the use of variable intensities of burning, which lead to greater variation in disturbance intensity.
- Conduct research into, and encourage the use of, natural regeneration systems for establishment of Douglas-fir.
- Include dynamic elements and flexibility in higher-level plans in order to allow for shifts in emphasis on species which require special attention, such as Douglas-fir, in order to take advantage of opportunities (i.e., large burns or insect outbreaks).



THE WILDLIFE HABITAT VALUES AND ATTRIBUTES OF DOUGLAS-FIR IN NORTHERN ECOSYSTEMS: STRUCTURAL AND FUNCTIONAL DIVERSITY

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INTRODUCTION

In the north-central interior, British Columbians have observed the amount and distribution of Douglas-fir across the landscape appears to be changing. This study is part of a problem analysis (*Ecology and Management of Douglas-fir in Northern Ecosystems*) which addresses the concerns that have been expressed by managers and Land and Resource Management Plan (LRMP) tables in the Prince George Forest Region. There was concern over the potential effects of loss of Douglas-fir from the landscape and on the availability of associated wildlife habitat in Fort St. James, Prince George and Vanderhoof Forest Districts. Some of the important issues that were identified included:

- the role of Douglas-fir as mule deer winter range;
- the values of Douglas-fir for wildlife tree users including primary and secondary cavity nesters; and
- habitat available for smaller mammals and predators, specifically the pine marten.

These issues are of particular concern in the Fort St. James Forest District where Douglas-fir reaches the northern limit of its range in conjunction with the northern limits of mule deer habitat in the interior. Little is known about the possible associations of mule deer or other wildlife species with Douglas-fir in this area and few inventories are available for wildlife species using Douglas-fir in these forest districts. Distribution and stand structure of Douglas-fir are different enough in the northern interior that studies done in more southerly areas are not applicable.

In this analysis, habitat attributes of the Douglas-fir stands were used as indices for structural and functional diversity to interpret and identify landscape-level habitat availability for selected species. Habitat attributes, including the structural diversity of stands, were assessed with three types of indices: (a) wildlife tree plots; (b) browse and pellet transects; and (c) coarse woody debris transects.

WILDLIFE TREES

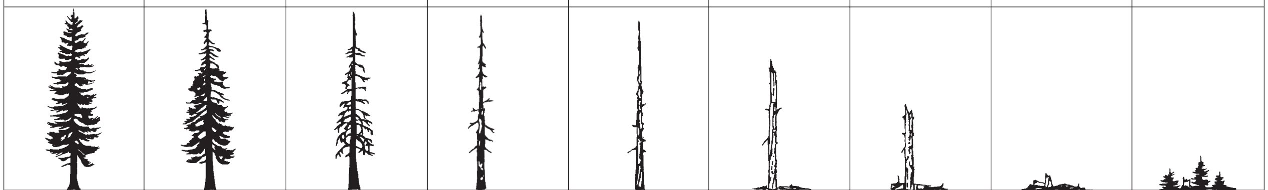
Wildlife trees are used by a multiplicity of organisms, including invertebrates, small mammals, larger mammals, birds and amphibians. These trees serve such needs as roosting, nesting, denning, feeding, perching, foraging, display and hunting (Machmer and Steeger 1995). A wildlife tree is defined by the British Columbia Wildlife Tree Committee as "any standing dead or live tree with special characteristics that provide valuable present or future habitat for the conservation or enhancement of wildlife" (Guy and Manning, 1995). Wildlife trees must also be $\geq$ 10 cm dbh in diameter (generally accepted that this is the minimum size of tree used for cavities) and $\geq$ 1.3 m in height (those stumps smaller than 1.3 m in height are considered coarse woody debris). Wildlife tree users serve important ecological functions. Some wildlife tree dependent species contribute to the regulation of forest pests, others consume and transport fungi, disperse seeds, and all species enhance the nutrient cycling of forest ecosystems.

The spectrum of wildlife tree classifications in Figure 1 (Ministry of Forests, 1996a) runs from Class 1 (live and healthy) to Class 9 (decaying debris). Each category of wildlife tree offers different habitat uses to a number of species; thus, a mixture of wildlife tree classes and different tree species across the landscape is the optimal means of providing the broadest habitat to the largest number of wildlife species.

Live/healthy trees (Class 1) offer nesting, roosting, perching for eagles, osprey, raptors and scavengers among others. Live/unhealthy (Class 2) trees offer nesting and roosting habitat for primary cavity nesters (strong woodpeckers) and secondary cavity users (small owls, nuthatches). Numbers of cavities will increase with the age and diameter of tree and wetter sites receive relatively less use. Nesting availability is a limiting factor for woodpeckers, generally, woodpeckers will nest in trees with a dbh greater than 30 cm dbh and a minimum of 15 m in height (Steeger and Machmer, 1995). These primary cavity excavators depend on trees with varying degrees of heartwood decay surrounded by a firm sapwood shell to provide protection from the elements (preference is shown for deciduous components such as aspen or birch, when available) (Keisker 1996). They also require dead standing trees and course woody debris for feeding.

The example of cavity nesters emphasizes the need for trees of a variety of decay classes and different species mixtures as they may nest in the live/unhealthy trees found in Classes 1 to 3, but feed on standing dead debris, stumps and woody debris from Classes 3 through 9 (Keisker 1996). Class 3 and 4 trees are also

FIGURE 1. British Columbia's Wildlife Tree Classification System



	LIVE		DEAD					DEAD FALLEN	
Decay Class	1	2	3	4	5	6	7	8	9
Description	**Live/healthy;** no decay; tree has valuable habitat characteristics such as large, clustered or gnarled branches or horizontal, thickly moss-covered branches.*	**Live/ unhealthy;** internal decay or growth deformities (including insect damage, broken tops); dying tree.*	**Dead;** needles or twigs may be present; roots sound.	**Dead;** no needles/ twigs; 50% of branches lost; loose bark; top usually broken; roots stable.	**Dead;** most branches/ bark absent; some internal decay; roots of larger trees stable.	**Dead;** no branches or bark; sapwood/ heartwood sloughing from upper bole; decay more advanced; lateral roots of larger trees softening; smaller ones unstable.	**Dead;** extensive internal decay; outer shell may be hard; lateral roots completely decomposed; hollow or nearly hollow shells.		**Debris;** downed trees or stumps.
Uses and users	Nesting (e.g., Bald Eagle, Great Blue Heron colonies, Marbled Murrelet); feeding; roosting; perching.	Nesting/ roosting[1] - strong PCEs[2] (woodpeckers); SCUs[3]; large-limb and platform nests (Ospreys); insect feeders.	Nesting/ roosting - strong PCEs; SCUs; bats.	Nesting/ roosting - strong PCEs; SCUs; insect feeders.	Nesting/ roosting - weak PCEs (nuthatches, chickadees); SCUs; bats; insect feeders.	Weaker PCEs; SCUs; insect feeders; salamanders; small mammals; hunting perches.	Insect feeders; salamanders; small mammals; hunting perches; occasionally used by weak cavity excavators such as chickadees.		Insect feeders; salamanders; small mammals; drumming logs for grouse; flicker foraging, nutrient source.

[1] Large witches' brooms provide nesting/denning habitat for some species (e.g., fisher, squirrels).
[2] PCE = primary cavity excavator
[3] SCU = secondary cavity user
* This classification system does not recognize root disease trees explicitly. Such trees become unstable at or before death.
Resources Inventory Branch, Vegetation Resources Inventory Sampling Procedures For Wildlife Trees (BC Min. of Forests, 1996)

used by other species (such as the bald eagle) for roosting and perching. Class 5 snags tend to be used by the weaker cavity nesters, bats and salamanders among others. Bats will use old abandoned cavities; a number of bat species have been red-listed.

Class 6 trees are used by insect feeders, salamanders and small mammals. Class 7 and 8 trees also provide sources of insects for insectivores, and are used by a variety of small mammals and salamanders. Other wildlife trees users include the red squirrel, larger owls which nest in open nests and use the trees for perching and hunting, and smaller owls which may use old cavities for nests. Black bears will use larger Douglas-fir trees as den sites, and will forage in these sites (Guy and Manning 1995).

Several barriers and difficulties are encountered by managers in providing wildlife trees. Traditionally the wildlife trees left after cutting were snags (usually with an obvious nest or perching platform), defined as a dead tree standing over three m in height. Other trees that could be left as wildlife trees without affecting the timber supply review or volume of timber harvested in a calendar year were the "dead potential" trees (standing >50% sound), and the veterans of >100 years age difference (40 years for lodgepole pine) from the surrounding immature stand contributing <5% of the stand volume.

Snags present dangers to the safety of workers according to the Workers' Compensation Board of BC. Section 60.38 of the Industrial Health and Safety Regulations states: "Where practical, snags shall be felled: (a) progressively with the falling of other timber, and (b) before felling adjacent live trees." If workers are going to be working in the vicinity of any snag, it has to be cut down.

Thus, it would be advantageous to leave patches of wildlife trees surrounded by no-work zones. Carefully selected patches (according to the biodiversity guidelines) will provide optimal habitat for a diversity of species of wildlife and can be combined with buffers containing no danger trees and some individual wildlife tree retention.

Another important point is that all trees are potentially wildlife trees and standing live, unhealthy, or dead trees each offer special characteristics valuable as habitat for the conservation or

TABLE 1. A comparison of timber grades and utilization with coarse woody debris decay classes.

<table>
<tr><th>Coarse Woody Debris Class</th><th>Volume Calculations -Dimensions</th><th>Timber Grade Possibilities</th><th>Dimensions</th><th>Utilization</th></tr>
<tr><td>1</td><td>›7.5 cm in diameter any length</td><td>Sawlog, 3,4,6,Z
• Various piece sizes greater than 3 m in length and larger than 5 cm in radius</td><td rowspan="5">Stumps no higher than 30 cm

Diameter at dbh
• lodgepole pine above 15 cm
• other species above 20 cm

Top diameter
• for all species and ages above 10 cm

Minimum length log or slab 3 m</td><td rowspan="5">stump heights: ‹30 cm
top diameter:
›15 cm mature
›10 cm immature

slab thickness:
›15 cm mature
›10 cm immature

minimum length: 3 m except bucking waste
›50% firmwood</td></tr>
<tr><td>2</td><td>same</td><td>3,4,5,6,Z
• Potential for chips only
• Lumber reject</td></tr>
<tr><td>3</td><td>same</td><td>4,5,6,Z
• Potential for chips only
• Lumber reject</td></tr>
<tr><td>4</td><td>same</td><td>Not applicable</td></tr>
<tr><td>5</td><td>same</td><td>Not applicable</td></tr>
</table>

enhancement of wildlife. A range of habitat attributes should be maintained through a diversity of wildlife trees at different stages of decay and health, structure, species of tree, age, and condition (including the percentage of bark on the tree, condition of wood, etc.) to create the best habitat for wildlife. It is also critical to consider the geographic location of the wildlife trees and the surrounding habitat features (for example, perching trees that are not adjacent to open forest or hunting habitat will not be useful). Wildlife trees should be managed at a landscape level in order to provide for functional diversity of ecosystems. From the landscape level, priorities should be set for site specific management where the specific requirements of individual species can be managed.

COARSE WOODY DEBRIS

Coarse woody debris (CWD) performs a number of important ecological roles. It creates habitat for a number of invertebrate and vertebrate species; influences geomorphology of small streams and slopes; affects microclimate conditions; acts as a nutrient and moisture pool; and, provides long term carbon storage.

Coarse woody debris is defined by the *Vegetation Resources Inventory Sampling Procedures* as "dead woody material, in various stages of decomposition, located above the soil, larger than 7.5 cm in diameter (or equivalent cross-section), which is not self-supporting (such as trees or stumps)" (Ministry of Forests 1996b). Five decay classes of CWD are specified by the Inventory Sampling Procedure (see Table 1 and Figure 2). Maintaining a diversity of CWD sizes and decay classes contributes to maintenance of biodiversity.

In terrestrial ecosystems CWD provides,

- sites for nests, dens and burrows;
- food for invertebrates and a growth substrate for fungi and some vascular plants;
- hiding cover for predators and protective cover for their prey;
- moist microsites (for amphibians, insects, plants and ectomycorrhizal fungi);
- travel ways across streams, across the forest floor and into subnivean areas; and
- refugia during disturbance.

CWD also provides structure and habitat in streams which allows for food accumulation and protective cover (Stevens 1996).

Fur bearers such as pine marten have a preference for sites with large volumes of CWD. Stumps and snags provide travel corridors (particularly for subnivean travel) and habitat for prey. Lynx and fishers den in CWD, and amphibians, such as salamanders and frogs, use the CWD as hiding cover. Douglas-fir tends to be of larger diameter than other tree species and, due to the nature of the bark, it can remain intact longer. Thus, the debris is more decay-resistant and remains on the ground longer than debris from other species. It can take ›1000 years for the complete decay of large individuals of some tree species (Douglas-fir and others) in some ecosystems.

FIGURE 2. British Columbia's Course Woody Debris Classification System

	Log decomposition Class 1 	Log decomposition Class 2 	Log decomposition Class 3 	Log decomposition Class 4 	Log decomposition Class 5 
	Class 1	**Class 2**	**Class 3** Figure 5-8	**Class 4**	**Class 5**
Wood Texture	Intact, hard	Intact, hard to partly decaying	Intact, hard to partly decaying	Small, blocky pieces	Many small pieces, soft portions
Other Characteristics					
Portion on Ground	Elevated on support points	Elevated but sagging slightly	Elevated but sagging slightly	All of log on ground, sinking	All of log on ground, partly sunken
Twigs ‹3cm (if originally present)	Present	Absent	Absent	Absent	Absent
Bark	Intact	Intact or partly missing	Trace	Absent	Absent
Shape	Round	Round	Round	Round to oval	Oval
Invading Roots	None	None	In sapwood	In heartwood	In heartwood

The above table is derived from Coastal Douglas-fir. Some of the characteristics used to define each class may not apply to different species of CWD
Resources Inventory Branch; Vegetation Resources Inventory Sampling Procedures for Coarse Woody Debris, (BC Min. of Forests, 1996)

MULE DEER

Mule deer in the northern interior are at the northern limit of their range and are dependent upon Douglas-fir stands to provide thermal cover, safety cover, snow interception, and food sources. Winter is a critical period for mule deer as food sources are scarce and energy expended on moving through snow and keeping warm can cause a net loss of energy. Douglas-fir trees offer more extensive canopy closure than mature trees of other species. The canopy creates snow interception, which facilitates foraging and movement by mule deer. These trees also supply important sources of lichens and litterfall which were found by researchers in the Cariboo Region to be critical to the mule deer winter diet (Armleder and Dawson 1992). These researchers also found that uneven-aged stands offered better forage and thermal cover for the mule deer. Although some studies suggest that the mule deer are critically associated with Douglas-fir, Davis (1994) found that the deer selected winter ranges based on aspect and elevation rather than on forest cover species (warmer south aspects were preferred possibly due to the shallower snow depth and more consistently settled snow pack). The question of whether deer select Douglas-fir requires further study, but we did examine the mule deer use of the plots that we visited. In order to find an index of use for the mule deer, we counted pellet groups and did browse transects. These methods were implemented according to the RIC standards elaborated in *Describing Terrestrial Ecosystems: Field Manual* (Ministry of Forests 1996c).

CONCLUSIONS

Wini Kessler posed the question "What will the landscapes of the future look like and will they be impoverished if Douglas-fir is diminished?" An exploration of the wildlife values and attributes of Douglas-fir suggests that the landscape would indeed be impoverished with a loss of this species. Douglas-fir has been found to form snags more often than other tree species as they are less susceptible to tree uprooting and are comparatively larger at tree death. These trees contribute to the component of wildlife trees, and ultimately the course woody debris component of wildlife habitat. Larger diameter CWD is naturally more decay resistant and offers longer term nutrient and moisture storage.

The Forest Practices Biodiversity Guidebook emphasizes the objective of managing forests to resemble forests established by natural disturbance. The natural state of a forest is highly variable, and the effects of disturbance on wildlife trees and coarse woody debris are little understood. The numbers that we gathered can be used as targets if the different types of measurement can be standardized. More information has to be collected on the optimal levels of CWD, and how these levels can be managed through time from an array of wildlife trees through to a full spectrum of coarse woody debris decay classes.

Wildlife tree patches containing mature trees, appropriately located, would provide mule deer habitat. Leaving a range of classes of wildlife trees in the patches could also create habitat for cavity nesters, and when combined with course woody debris, may offer small mammal habitat and possible habitat for some furbearers (depending on the size of the patch and location). It is recommended that managers use adaptive management, including information collection before different harvesting techniques are employed, and follow-up studies to determine the effect of treatments. This will improve understanding of the impacts of different management scenarios through time. Information is gathered through monitoring responses of wildlife to different treatments (such as spacing, brushing, size of opening and partial cutting) and the information gained is used to adapt management strategies to achieve the desired goal. An increase in the structural and functional diversity of wildlife trees and coarse woody debris managed over the landscape will contribute to increased habitat availability and will promote sustaining natural biodiversity.

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DOUGLAS-FIR SILVICULTURE "ON THE EDGE"
SILVICULTURAL SYSTEMS AT THE NORTHERN LIMIT OF THE SPECIES

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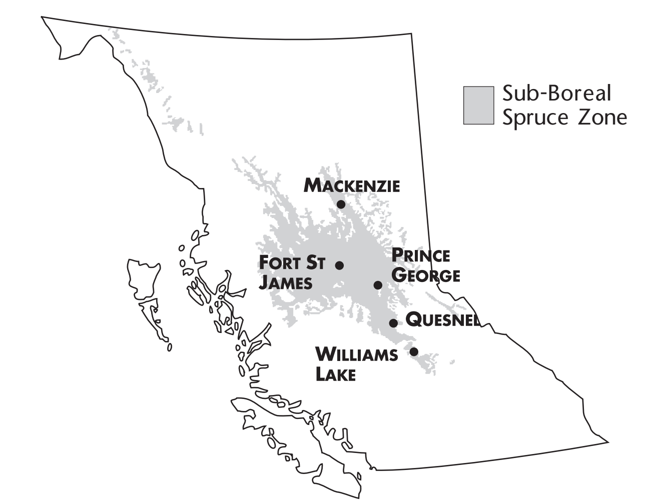
INTRODUCTION

During this workshop, the many presenters have provided an excellent summary of current knowledge of the natural history, silvics, ecosystem dynamics, and value of the Douglas-fir forest type in British Columbia and western North America. Two strong themes have emerged: first, there are many more similarities than there are differences among Douglas-fir ecosystems throughout its range; second, understanding of the growth, development, and function of Douglas-fir ecosystems has changed remarkably over the last several decades. We now manage not just for wood production, but also maintenance of biodiversity, ecosystem health, wildlife habitat, visual quality, and many other objectives. Many of these goals would not have been considered by silviculturists in the past, but are now important considerations in silviculture prescriptions.

The original working title of this paper was "*Timber management in northern Douglas-fir.*" Timber management is a term not heard much in these days of the more general and palatable term "integrated resource management." To broaden the focus of our discussion from traditional stand and forest management methods to both traditional and potential future applications of non-traditional methods, the title was revised to "silvicultural systems" rather than "timber management." Semantics aside, however, there is surprisingly little difference between the two topics in many respects.

Figure 1. Average monthly growing season temperatures were examined at five locations.



While our forest management goals change over time to meet more complex societal demands, the primary methods and strategies needed to achieve these goals are remarkably traditional and durable. The philosophy and practice of forest management in British Columbia have changed dramatically in the last decade, but the main shift in practice has not been the invention of new tools or concepts, but the re-deployment of our existing tool kit of methods to meet different needs. Timber management may no longer be the sole driver of forest management, but many of the silvicultural methods developed originally for timber production provide useful tools for achieving a range of integrated resource management goals. These include: different regeneration methods, harvest methods, and silvicultural systems; management of forest age class structure, stand structure, and target rotation age(s); ecological site classification and site index; and stand growth modeling and prediction.

Determining appropriate silvicultural systems and timber management strategies for northern Douglas-fir involves asking some basic questions about the current and future status of fir in the Sub-Boreal Spruce (SBS) biogeoclimatic zone. Is Douglas-fir actually 'on the edge' of disappearing from the northern landscape, as some suggest? Certainly, it is widely feared that the species is in decline in the north. This perceived decline is a major focus for this workshop. The problems associated with regeneration and management of Douglas-fir in the sub-boreal are often interpreted as evidence of a threatened and vulnerable population. The central BC interior represents the northern edge of the natural range of Douglas-fir on this continent. Also, the sub-boreal forest is a cooler climate for much of the year compared to the montane Douglas-fir forests in the valleys and plateaus of the southern interior BC and western United States. It is temptingly easy to conclude that Douglas-fir in the SBS zone is a marginal or fringe species, barely surviving at the extreme physiological limits of its evolutionary range. But, is this assessment accurate?

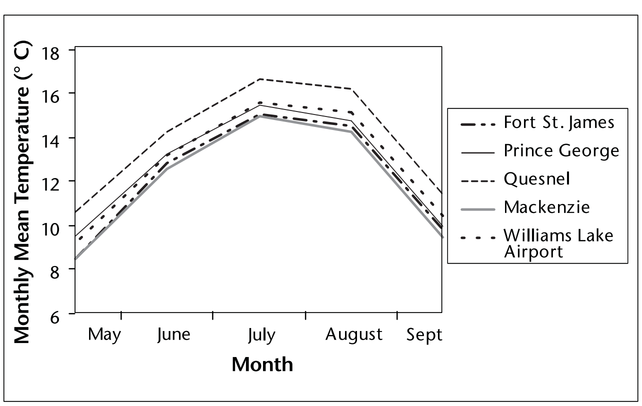
Northern Douglas-fir is often treated as merely an ecological curiosity that is protected and managed for heritage value, genetic conservation, biodiversity, and wildlife objectives, but no more than that. Fir management is seen as one more "non-timber" issue, and timber managers express concerns about the "reduced productivity" that allegedly results from managing Douglas-fir on sites where lodgepole pine would otherwise be planted. In contrast, seldom is heard a discouraging word about interior spruce and lodgepole pine as these are widespread sub-boreal and boreal tree species with productive natural ranges extending far to the north. Their use is extensive and little questioned. Is Douglas-fir truly a second-rate silvicultural choice to spruce and pine? And what should our expectations be for short- and long-term growth performance of Douglas-fir?

Apparent threats to Douglas-fir abundance in the SBS are numerous, but are often relatively anecdotal and poorly quantified. There seem to be "lots" of big Douglas-fir logs being trucked out of the forest, but spruce and pine plantations seem to nearly "always" replace the harvested old stands which previously had a former Douglas-fir component. Fir mortality from infestations of Douglas-fir bark beetles are chronic in many areas with extensive mature fir, and bark beetles are viewed as a relentless threat that will "inevitably" wipe out these stands unless they are clearcut harvested and removed.

It seems that much mature Douglas-fir co-existed with the bark beetle in times past without our "forest health" interventions, but now for some reason, we need to "manage" the "problem." Or, perhaps have we failed to perceive how ecosystem dynamics have been altered in some way by our forest management at a landscape scale? Once fir stands are clearcut, can we count on the Douglas-fir component to be renewed? Historical problems with trying to regenerate Douglas-fir in clearcuts have caused many foresters to simply replace fir with apparently more reliable species, such as lodgepole pine.

Alternative silvicultural systems, including partial-cut systems, or even-aged hardwood-conifer mixtures (or "mixedwoods") such as paper birch/Douglas-fir mixtures, are proposed as a means of regenerating Douglas-fir and potentially avoiding the regeneration problems associated with conventional clearcutting (DeLong, Simard, Beaudry, Oneil, this proceedings). However, use of these methods is in their infancy in the SBS zone. Results of operational research trials are very preliminary. To date, apart from southern experience with selection systems for interior Douglas-fir, there is little local guidance available on how to operationally implement and manage these systems.

Figure 2. Mean Monthly Growing Season Temperatures across the Northern Range of Douglas-fir.



To select and prescribe appropriate silvicultural systems for northern Douglas-fir without local experience with different options, we need to examine other potential information sources about the species, its natural history in the SBS zone, and past history of management. Four key points are: (a) identifying the distribution of the Douglas-fir type in the northern SBS; (b) the factors or processes important for successful fir regeneration, stand management, and productivity; (c) how have SBS fir stands naturally regenerated, what kind of stand structures have developed historically, and how can silvicultural systems emulate these stand structures; and (d) what are the objectives of management?

Because of the lack of published information on northern Douglas-fir, the information presented in this paper was collated from many sources, including climate summaries, operational timber sale information (cruise summaries), unpublished regional research data sets, and computer models. One of the long-term benefits of this workshop and proceedings will be an up-to-date central reference for northern Douglas-fir information and management.

GEOGRAPHY AND CLIMATE AT THE NORTHERN LIMITS OF DOUGLAS-FIR

At its northern limits, the range of Douglas-fir in northern British Columbia extends well into the Sub-Boreal Spruce Zone of the Fraser Basin and Fraser Plateau of British Columbia. To the west, Douglas-fir extends approximately to Fraser and Babine Lakes, to the east to the Rocky Mountains and into the Rocky Mountain trench where it is abundant, to the northwest to the Takla-Stuart Lake region, and to the Parsnip drainage in the northeast. Douglas-fir tends to be more abundant in drier SBS subzones and less so in wetter subzones, and occurs below about 1000 m, particularly on many warmer aspects and coarser soils. It is absent or extremely rare in the northwestern corner of the sub-boreal zone north of Tezzeron and Babine Lakes.

Is climate too severe and limiting to Douglas-fir growth as its northern range is approached? To examine this possibility, Canadian Atmospheric and Environment Services climate summaries were collated for a number of stations on a south-to-north transect through the SBS zone, from Williams Lake and Quesnel, BC in the Cariboo Region, northward through Prince George, Fort St. James, and Mackenzie BC.

Average monthly growing-season temperature data were examined at the five locations (Figure 1), for the period of May to September (Figures 1 and 2). Quesnel is warmer than the locations to the north throughout the growing season. However, Williams

Lake (an airport location further to the south but higher in elevation) closely matched the temperature of Prince George, Ft. St. James, and Mackenzie. Average frost-free period per year (Figure 3) again was generally somewhat longer in southern locations, but this trend is strongly modified by elevation and topographic location, not just north to south latitude. Although not presented, growing degree day data showed a similar trend to that for the frost-free period.

While there is an expected gradual decrease in growing-season temperatures and length of frost-free periods northward across the SBS zone, climate statistics for all five locations are still well within the range of values observed in many other locations in southern British Columbia and western United States where Interior Douglas-fir is abundant (Herrmann and Lavender 1990). In general, average climatic growing conditions do not seem to be more limiting to Douglas-fir than in other continental portions of its range. Where climatic factors do restrict the range of Douglas-fir in the north, these are more likely to be extreme events (frost events, ice storms) or limiting topographic conditions (e.g., frost pockets) (Steen *et al.* 1990) that reduce early growth and vigour of Douglas-fir.

In fact, the general trend in distribution of fir in the northern SBS zone is that the more favourable sites for fir are confined to warmer slopes and aspects where Douglas-fir can gain some protection from growing-season frosts and other extreme climatic events, and sloping, coarser droughty soils with open canopies. As a result, the rolling topography of the sub-boreal plateau, with a mosaic of different aspects, slopes, soils, and elevational bands fragments the distribution of Douglas-fir forest types (e.g., see DeLong, this proceedings). The question local silviculturists should ask about Douglas-fir growth and performance potential at its northern range should not be "*Will Douglas-fir grow well in the SBS*?" There is much evidence to support the case that it will. A better question is, "*On what sites will Douglas-fir grow well in the SBS*?"

THE NORTHERN DOUGLAS-FIR TIMBER RESOURCE: VITAL STATISTICS

For the casual observer, it is difficult to get a reliable sense of the extent and importance of the northern Douglas-fir resource, due to its irregular distribution at both the landscape and stand level in the SBS zone. Often Douglas-fir occurs as isolated veterans or dominants in stands made up primarily of other species, frequently as a secondary component of mixed stands, and more rarely, as a leading component of mixed or relatively pure stands. Historically, resource managers have tended to underestimate the significance of the resource due to the inconspicuous nature of fir among seemingly vast tracts of pine and spruce.

As well, individual forest districts and forest licensees seldom have enough fir types or fir component in their stands to consider it to be a major part of their forest profile or regeneration concerns. In some areas with a predominantly small pine or spruce timber profile, harvested Douglas-fir has been shipped elsewhere as its milling requirements and large piece size often meshed poorly with mill technology designed for high production of smaller pine.

These milling difficulties have frequently influenced the choice not to regenerate fir on many sites where it has been harvested in considerable volume. The assumption that today's silviculture should be tailored to produce only the products that today's local milling technology will handle (and that milling technology will be unable to adapt despite one-rotation lead times of 80 to 120 years) seems to hold much sway in some quarters. To put this assumption in perspective, consider that thirty to forty years ago, lodgepole pine was a "weed species," and large fir was the staple of many mills around Fort St. James and Prince George. The change in milling facilities to process large volumes of small-diameter pine is a phenomenon of only the last two decades, and not necessarily a permanent one.

To adequately assess the fir resource, we need to look at the big picture. Fortunately, a broad scale analysis is available from the Douglas-fir Reduction Study, an unpublished (1994) BC Ministry of Forests regional analysis of the Douglas-fir resource in the Prince George Timber Supply Area (comprising 3.62 million

Figure 3. Average length of frost-free period across the Northern Range of Douglas-fir.

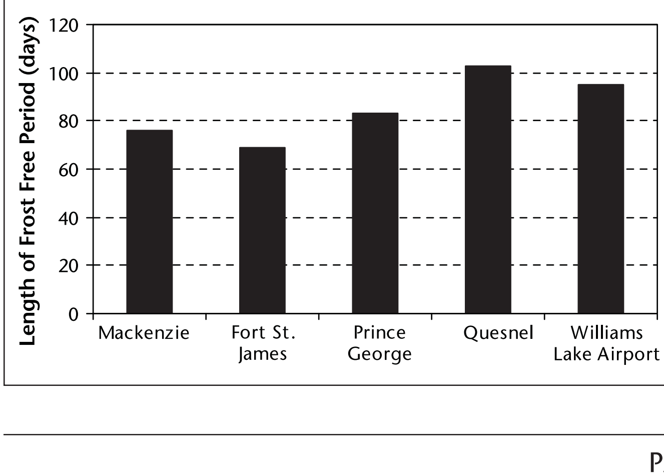
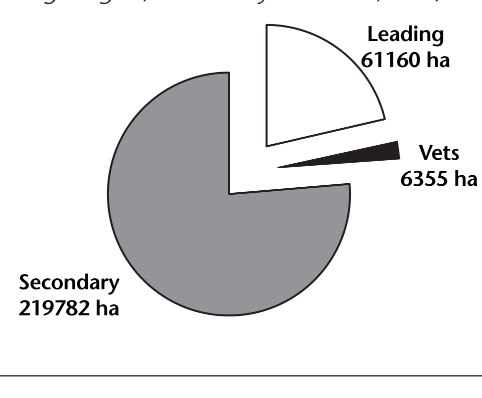


Figure 4. Area Summary of All Douglas-fir Types for the Prince George TSA *(Source: Douglas-fir Reduction Study Prince George Region, BC Ministry of Forests, 1994).*



hectares, including the Prince George, Vanderhoof, and Fort St. James Forest Districts).

Mature Douglas-fir-leading forest types comprise only 1.6 % (approximately 61,000 ha of a total 3.6 million ha) of the harvestable timber base in the Prince George TSA (Figure 4). However, this 1.6 % includes only those forest types in which Douglas-fir is the leading species by volume. There are an additional 220,000 ha of forest types in which fir is secondary or tertiary species by volume and 6355 ha where fir vets form the dominant layer. In total, forest types containing Douglas-fir in the Prince George TSA cover 288,000 hectares, or 8% of the total harvestable forest land base. The majority of this Douglas-fir area occurs in the Prince George forest district (76 % of total 288,000 ha), with less but significant areas in the Ft. St. James (15 %) and Vanderhoof (9 %) districts (Oneil, this proceedings).

Statistics for annual scaled volume of Douglas-fir harvested in the Prince George Region over the last 12 years (BC Ministry of Forests Annual Reports, 1982-1994) indicate that harvest is consistently in the 300,000 to 500,000 m^3 range (Figure 5). More recent statistics compiled for the three forest districts by Oneil (this proceedings) for 1989 to 1996 indicate that average annual scaled fir harvest for this period is 386,000 m^3/y. The Douglas-fir cut is about 4.3 % of the allowable annual cut (AAC) on an annual basis, based on an average Prince George TSA AAC of 9 million m^3. However, these past trends predate either recent biodiversity provisions of the Forest Practices Code, biodiversity and mule-deer winter range management guidelines being considered under LRMP processes, or Ministry of Forests' Douglas-fir management guidelines introduced recently in the Prince George, Vanderhoof, and Fort St. James Forest Districts. Douglas-fir harvest trends at a regional level may change over time from historic levels as current provisions are implemented.

Forest-level age-class distribution of northern fir types is a useful assessment criterion for obtaining a snapshot of the status, stability, and dynamics of the Douglas-fir forest type (Figure 6). In general, for Douglas-fir forest types as a whole, mature (> 120 years) and mid-aged (41 - 120 years) age classes are well represented, although with significant deficiencies in young age classes (0 -40 years). This trend is true for the Prince George and Fort St. James districts. For the smaller area of fir forest types in the Vanderhoof district, the age class distribution is dominated by mid-aged stands with lesser amounts of mature stands.

The Douglas-fir age-class distribution in the moist and drier SBS zone is typical of areas with relatively frequent history of natural disturbances, such as fire. In contrast, very unbalanced forest age-class structures are found in wet-belt spruce-balsam and cedar-hemlock forest types where natural disturbance has been less common. These are typified by large areas of mature and overmature age classes, few mid-aged stands, and increasing amounts of young early-seral age classes generated by clearcut silvicultural systems.

For Douglas-fir types, the extensive age-class structure in mid-aged and older age classes is due to the regeneration and renewal of mature stands by wildfire before the advent of fire control in the 1930s and '40s. The relative deficiency of young age classes (only 5400 ha of immature fir-leading stands and 35,000 ha total and 12% of the total Douglas-fir area) may be due to increasing fire control in more recent decades, as well as conversion of some mature fir-containing types to stands of other species through current clearcut and plantation practices.

Figure 5. Annual Douglas-fir Harvest Volumes, Prince George Forest Region.

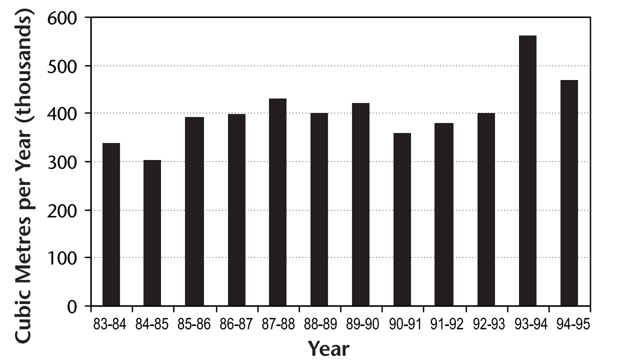
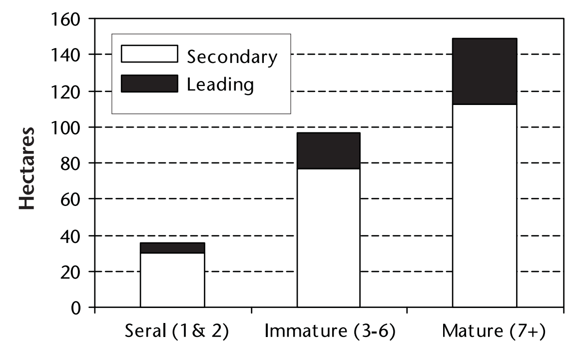


Figure 6. Age Class Distributions, Fir Types, Prince George TSA *(Source: Douglas-fir Reduction Study, Prince George Region, BC Ministry of Forests, 1994).*



The relative abundance of thrifty mid-aged stands is a source of potential replacement of mature stands in the landscape. This is favourable for the short- to mid-term future of northern Douglas-fir in the Prince George TSA. While we are legitimately concerned about the relative scarcity of younger fir plantations and natural stands in the SBS zone, a deficiency of older age classes would take longer to replace in the forest landscape. These mid-aged fir stands (including fir mixes) will, over time, gradually develop characteristics and functions of older stands, and gradually replace existing mature stands lost through harvesting, fir-beetle outbreaks, or fire.

Should we be managing northern Douglas-fir stands towards a balanced, fully-regulated forest age-class distribution in which there is equal area in all age classes (e.g., as per Davis and Johnson, 1986, pp 538-591)? No, not necessarily. The concept of the balanced (or normal) forest is derived from classical concepts of forest-level area-based harvest regulation. This concept was developed for even-aged management of whole forests for sustained yield of timber. This concept assumes that the entire forest area and stand management regimes will be relatively homogeneous — an unlikely assumption. As well, even if the balanced target is applied to the age class distributions of SBS Douglas-fir types, the target area of Douglas-fir in a given age class is not an absolute, but dependent on our choice of rotation age. For example, if we choose to manage fir on traditional interior sawlog rotations of 80 years, a balanced forest age-class distribution would contain 25% of the area of Douglas-fir types in each 20-year age class.

Based on this assumption, our existing fir age-class distribution is clearly "overmature" and unbalanced and we need to vigorously "liquidate" all old stands to balance the area of younger stands. In contrast, at an extended rotation of 160 years, a balanced forest age-class distribution would include 12.5% of the area of Douglas-fir types in each 20-year age class. If we start to examine the idea of longer rotations for Douglas-fir (Curtis and Marshall 1993), including commercial thinning and various partial-cutting practices in mid-aged and older stands, we need less area of younger stands to maintain the target age-class distribution of older stands and still maintain harvest rates. Use of partial-cut silvicultural systems allows management of younger and older age classes on the same hectare in two-aged or multi-aged stand structures.

Traditional forest-level planning and harvest regulation have assumed that eventually all mature stands in the operable forest area above the target rotation age will be harvested. This assumption would be strongly questioned today. Douglas-fir management in the north is a key, high-profile element of maintaining biodiversity and wildlife objectives in many SBS forest types. For Douglas-fir, management of mature forest and mature forest structural elements will be important. While fir will continue to be valuable for timber, its management will be subject to many non-timber objectives in setting silvicultural goals. Second, as fir is a small component of the overall timber supply area, local or regional variations in its age-class distribution will be of little impact in terms of long-term harvest regulation and age-class distribution of all forest types for the entire Timber Supply Area. In this perspective, we have tremendous flexibility in setting forest- and stand-level objectives for Douglas-fir. Recognizing this flexibility, we are freer to identify the real questions for forest level management of Douglas-fir in the northern landscape. These are:

a) what age-class distribution and mix of stand structures is desired to balance timber production and ecological objectives; and,
b) how do we manipulate stands to attain this objective?

STAND STRUCTURE, DYNAMICS, AND SILVICULTURAL SYSTEMS

We need to understand Douglas-fir mixed stand dynamics and typical stand structures in order to develop site-specific, appropriate prescriptions. To what extent can we draw on examples of southern interior practices? In general, there appear to be differences between northern Douglas-fir stand structures in the SBS zone, and those of Douglas-fir stands in southern BC and the western United States. Stands in the Interior Douglas-fir (IDF) biogeoclimatic zone and much of the Montane Spruce (MS) zone tend to be uneven-aged, multi-layered stands. Many IDF and MS stands have been repeatedly disturbed from natural patterns of frequent ground fires, by fire exclusion, repeated diameter-limit selective logging, *Armillaria* and *Phellinus* root rots, and heavy cattle grazing. Northern Douglas-fir stands in contrast. They are relatively even-aged to two-aged in structure, are usually relatively closed-canopied stands (particularly on moister sites), and, in most cases, have had only sporadic history of partial-cutting, except in more accessible areas along river valleys. Natural uneven-aged stands

Figure 7. Example of Douglas-fir Mixed Stand Structure and Composition, Butcher Flats *(Source: Clear Lake Sawmills CP537 Cruise Data).*

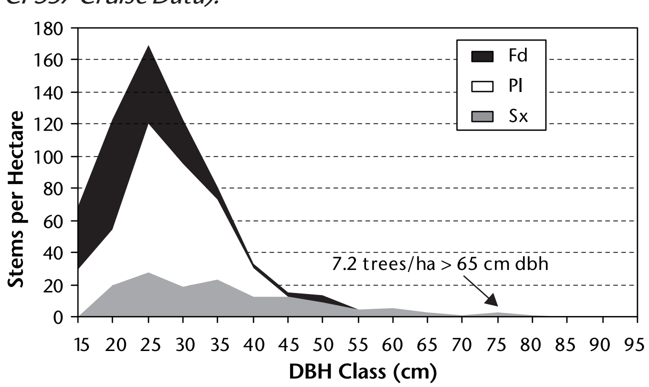
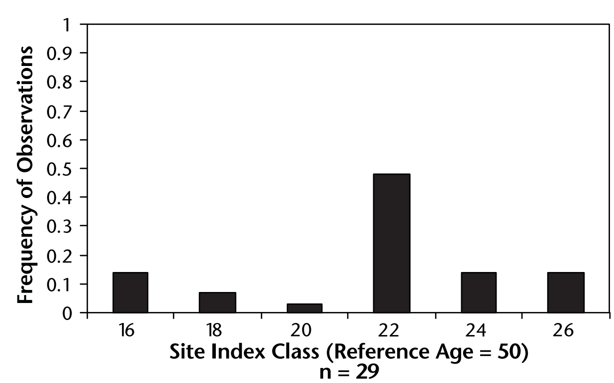


Figure 8. Site Index of Northern Douglas-fir, Prince George Region Growth and Yield Permanent Sample Plots.



in the SBS occur infrequently, on very xeric (droughty) sites such as bedrock or gravelly outcrops where lodgepole pine and other species have difficulty establishing or forming a closed canopy.

However, no published studies have examined demographic stand age structure or stand reconstructions of Douglas-fir stands in the SBS zone. We currently rely on interpretations of stand size structure to make assumptions about stand age structure and dynamics. Such interpretations are usually dubious at best and new field studies in this area would be a great benefit.

As noted previously, mixed stands of Douglas-fir as a secondary or tertiary species are the most commonly-occurring Douglas-fir forest type in the region. We now examine the size structure of one such relatively typical even-aged mixed pine-fir-spruce stand at Butcher Flats, south of Prince George (Figure 7). This case study is instructive for providing insights to potential stand dynamics and silvicultural system options in such stands.

The Butcher Flats stand had an average age of approximately 130 to 140 years, with total merchantable volume of 411 m^3/ha. The stand was harvested in 1995/96. Pine and fir each comprised 40% of the merchantable volume, although pine comprised 40% of the stems-per-hectare and fir only 28%. Spruce, along with paper birch and trembling aspen, made up the remaining 20% of the stand volume.

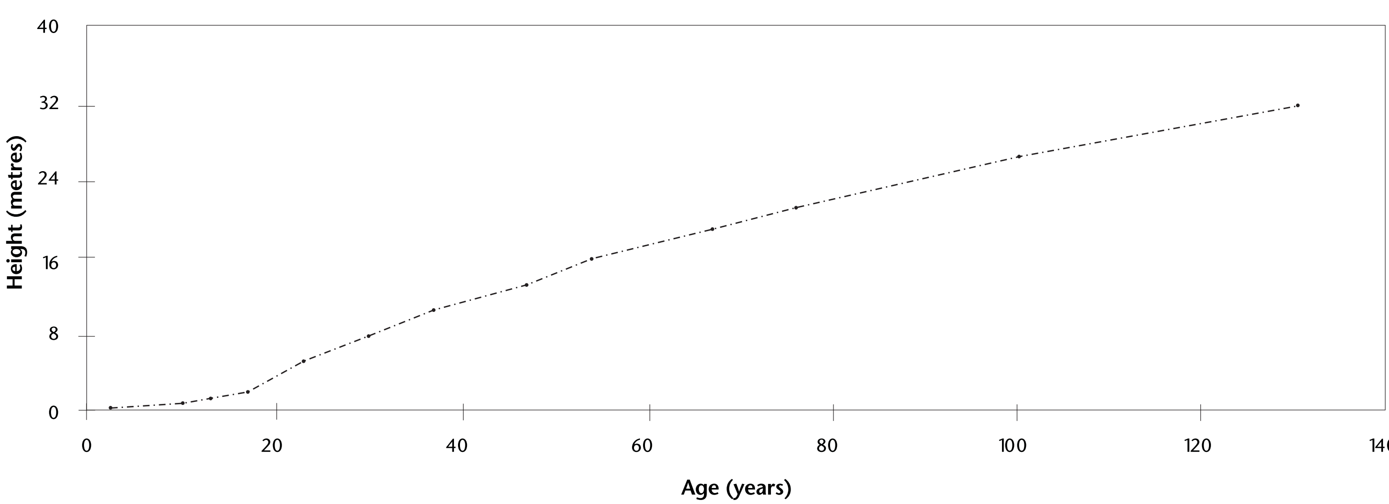
Notable of many mixed Douglas-fir stands of this age or older was that fir tended to dominate the upper canopy stratum and larger diameter classes of the stand, while the pine was shorter, had poor vigour, and in this case, was subject to mountain pine beetle attack. Typically, the dominant fir layer was assumed to be a vet layer (i.e., all the fir was older than the pine). Spruce occupied the understorey and small diameter classes and was either a successional younger age class, or was actually of similar age but had been outgrown by pine and fir during earlier stages of stand development. The diameter distribution of Douglas-fir in this stand appeared to be bimodal — that is, fir had two distinct size-class ranges — in the stand. One size class was composed of very large scattered veterans between 60 and 100 cm dbh, and the second size class ranged from 20 to 60 cm dbh. Although detailed age data are not available, this size distribution suggests the existence of two distinct age classes of fir — scattered fir veterans which probably survived a previous stand-initiating fire, and younger, more heavily-stocked, and smaller-diameter age class which seeded in from surviving veteran seed trees.

This distribution of size classes and species in this stand suggests a stratified single-cohort (single aged) mixed stand with scattered individuals of an older cohort which are survivors of the stand-initiating disturbance (Oliver and Larson 1990). Future stand reconstruction studies (Larson 1986) would be an ideal means of identifying long-term stand development and height growth trends in such stands. An important point relating to appropriate choice of silvicultural systems and individual leave trees is raised from this discussion. The Butcher Flats prescription in this case specified that all fir >40 cm dbh must be reserved from cutting (approximately 38 sph).

However, in a two-age stand with veterans and younger mature trees, all the Douglas-fir trees above a certain size class may not necessarily be of the same age or have the same physical characteristics, due to differing patterns of growth and development. The common practice of leaving behind scattered Douglas-fir reserves in a cutblock and assuming that all large fir are windfirm "veterans" may be very risky. Many fire-origin Douglas-fir stands have a relatively densely-stocked younger even-aged cohort. These trees are unlikely to have the same crown characteristics, stem taper, and root development as true veterans which adapted to open conditions after a past wildfire.

Trees grown under dense stand conditions tend to have small crowns with little taper, and small root systems. These trees are more likely to have poor individual windfirmness, and are likely to be poor choices as isolated leave trees in clearcut conditions. Intact stands which may be windfirm under fully-stocked pre-harvest conditions may mask possible restricted rooting of the individual trees. If rooting characteristics of the soil are not carefully checked at the prescription stage, this deficiency will only become

Figure 9. 127-year Douglas-fir Height Growth, Log Lake, SBSmk1 subzone, SI(50) = 19 m.



evident when the isolated individual trees start to blow down after logging. Care must be taken to screen candidate blocks and treatment units where leave tree retention is being considered, to identify relatively well-drained soil types with good rooting characteristics, and to carefully inspect candidate leave trees. Arbitrary diameter-limit approaches for specifying leave-trees seldom provide good results in these respects. The type of reserve (single-tree or groups), shape, orientation, and placement of reserves, must be considered carefully to avoid undue wind damage (Stathers *et al.* 1994).

It is a common view among many foresters that Douglas-fir is always naturally windfirm, based on some examples of natural seed-tree situations formed after natural disturbances, such as fire. However, site factors, especially soil characteristics, tend to be much more important determinants of stand windfirmness than species in evaluating rooting character of trees (Sutton 1991). On unfavourable sites or soil types, soil characteristics such as restricting layers will make Douglas-fir just as susceptible to shallow-plate rooting and windthrow as any other species on the same soil type.

Examples of natural seed trees are usually examined a decade or several after the disturbance, and we see only the *survivors* of any post-harvest mortality of the leave-trees that may have taken place after the initial disturbance. Some field observations suggest that, after a natural disturbance, a significant number of remnant firs with inferior characteristics are eliminated over time by wind and biotic agents, leaving only the more stable, better-suited individuals. However, these observations are now only beginning to be carefully studied or documented. Foresters prescribing partial-cut silvicultural systems often strive to copy some of the stand structures generated by natural disturbances.

However, to minimize the post-harvest losses probably endemic to these situations, silviculturists need to develop skills for identifying desirable and undesirable leave-tree or reserve characteristics. In denser stands with poorer crown and root development, gradual wind "conditioning" of future leave-trees, through initial partial-cut stand entries such as shelterwood preparatory cuts, may be necessary. Finally, expectations and management practices may need to be adjusted to routinely anticipate some post-harvest losses of Douglas-fir leave trees after partial cutting. Retrospective examination of past partial-cuts and veterans of natural disturbances such as fire is a useful strategy to better understand the physical characteristics that allow certain individuals to be successful survivors after disturbance.

Figure 10. Annual Douglas-fir Seedlings Planted, Prince George Forest Region.

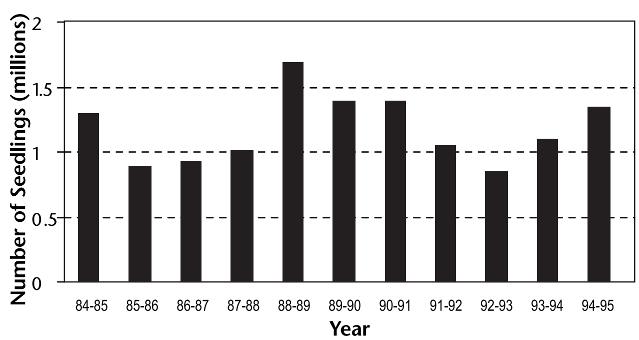


Figure 11. Characteristics of More Windfirm Douglas-fir Leave Trees

* Dominant or Co-dominant
* Live Crown > 40%
* Height to Diameter Ratio < 60 to 65 (highly tapered)
* Open-grown crown character
* Good rooting, soils

PRODUCTIVITY AND ROTATION LENGTH OF NORTHERN DOUGLAS-FIR SITES

It is well established that lodgepole pine outperforms Douglas-fir in early height growth in many of our plantations and natural stands. For example, height growth performance in EP 660, three 25-year old plantation trials of lodgepole pine, Douglas-fir, and white spruce, indicates that Douglas-fir is consistently about 20 % shorter than pine, primarily due to impacts of abiotic damage (Coopersmith *et al.*, this proceedings). It is frequently assumed that this difference applies to volume yield as well as height growth, and that this advantage will continue or increase over a whole rotation. Is this assumption correct? Central questions regarding productivity of northern Douglas-fir also include: What volume growth or mean annual increments (MIAs) should be expected in northern Douglas-fir stands? What are the long-term growth patterns in Douglas-fir, and how might these influence long-term stand development in stands containing Douglas-fir?

There are few long-term growth-and-yield permanent sample plot (PSP) data in natural Douglas-fir-containing stands in the Prince George Forest Region. Only five plots in the region have more than five years of data (one remeasurement period) and most of the 29 plots established in Douglas-fir types in the region have been established in the last five years.

However, the initial plot establishment information from these plots is a useful sample of the range of typical site indices and site productivities for Douglas-fir sites in the Prince George Region. The PSP site indices range from Site Index at 50 Years (SI_{50}) of 16 m to 24 m, with an average site index of 19 to 20 m (Figure 8).

To provide a rough approximation of expected yield and stand development for typical plantations of Douglas-fir on sites of average productivity in central BC, the Ministry of Forests Research Branch ran its growth and yield models WINTIPSY and TASS (Tree and Stand Simulator) for Interior Douglas-fir stands of site index 19 at 50 years (average for region based on the growth and yield plots) and initial stand density of 1200 stems per hectare. Stands were modelled to a maximum age of 150 years. No operational adjustment factors (OAFs) were applied to the model.

Results of this one model run (DiLucca, fax communication, Sept. 1997) were as follows: To age 100, projected mean annual increments (MAI) are 5.12 m^3/ha/y, with total merchantable yield of 512 m^3/ha. Interestingly, although MAI culminates (reaches a maximum) at 100 to 110 years, MAI is sustained at 90% or greater of the maximum MAI between 75 and 150 years of age or more. This MAI trend suggests that there is significant flexibility for management of Douglas-fir on longer rotations with little loss of increment. Of course these models must be interpreted with some caution until calibrated more thoroughly for northern Douglas-fir forest types in the SBS zone, tested with a variety of stand management scenarios, and applied with realistic operational adjustment factors.

Additional intriguing evidence for long-term sustained growth of fir to advanced ages is found in a data set of fir height growth (P. Sanborn and M. Kranabetter, unpublished data) collected from stem analysis data in the pre-harvest stand at the Long-term Soil Productivity (EP 1148) installation at Log Lake, 60 km due north of Prince George, BC. This mesic site is located in the SBSwk1 subzone at approximately 800 m in elevation, and has a site index of around 20, close to the regional average. The original stand was even-aged, 127 years of age, and contained a mixture of spruce, Douglas-fir, and some pine and hardwoods. Similarly to the Butcher Flats stand, Douglas-fir formed the dominant canopy strata, while spruce and pine formed the codominant strata.

The average height growth trends of Douglas-fir, reconstructed by destructive stem analysis of 30 stems (Figure 9) indicate that height growth, though initially slow in the first two to three decades following establishment, increased after this period and remained fairly steady right up to harvest at an average height of 33 m at 127 years. At harvest, Douglas-fir was on average approximately 3 m taller than the spruce and 7 to 8 m taller than the lodgepole pine of the same age. Unfortunately, live pine was too scattered in this stand to sample for height growth trends. Because of its large size and height, fir in this stand were initially thought to be veterans of a previous stand that were older than the pine and spruce. The stem-analysis data suggested that stratification of species and dominance of fir in the canopy was due to sustained height growth of Douglas-fir relative to other tree species in the stand of the same age.

At what age Douglas-fir overtakes pine in height in mixed pine-fir stands is not clearly known. Estimates based on local field experience and observations are that fir surpasses pine around 60 to 80 years of age. Analyses of predicted height growth trends from site index curves for pine and fir (Oneil *et al.* 1997) suggest that Douglas-fir height growth will exceed pine after age 50 (although these assume height growth for both pine and fir is compared under open-grown conditions). Again, what is really needed is more extensive stand reconstruction work in the northern SBS to test these trends and observations more rigorously and on a wider scale for mixed stands of fir and other species.

Based on local evidence and analyses, extended rotations up to 150 years or more appear to be realistic and suited to the long-term pattern of Douglas-fir stand development and volume increment. Long rotations would hold tremendous biological and silvicultural potential for achieving a wide range of stand-level objectives (e.g., aesthetic, wildlife habitat, etc.) while developing very large piece size, high timber quality, and maintaining high mean annual increments. A technical commentary and review of the subject by Curtis and Marshall (1993) make a compelling case for dramatic reappraisal of old-rotation concepts for Douglas-fir. This article, by respected long-term growth and yield researchers in the US Pacific Northwest, is recommended reading for Douglas-fir managers and silviculturists. As Curtis and Marshall conclude:

> *"Culmination age in Douglas-fir is later than many people think, and very short rotations involve substantial losses in long-term production. The MAI curve is relatively flat near and beyond culmination, suggesting a considerable range of rotation ages would produce about the same MAI . . .*
>
> *We need to rethink the whole question of harvest age and rotation length, as part of the current general reappraisal of management practices. Political and social pressures are forcing radical change, and traditional narrow economic analyses have little relation to current realities. Extending rotations may be one of the least disruptive and most effective ways to adapt."*

CURRENT SILVICULTURAL PRACTICES FOR NORTHERN DOUGLAS-FIR

How much Douglas-fir has been planted in the Prince George Region? Statistics available from BC Ministry of Forests Annual Reports from 1983/84 (the earliest year statistics are available by species) to the present indicate that,since that year, the number of Douglas-fir seedlings planted has ranged between 1 and 1.5 million per year for the Prince George Region (Figure 10).

Assuming an average planting density of 1600 stems per hectare, this volume of seedlings is the equivalent of an average 800 to 1000 hectares planted per year. Even accounting for planting of Douglas-fir in the Robson Valley District, it is estimated that approximately 600 to 750 hectares or more of Douglas-fir are planted per year in the Fort St. James, Vanderhoof, and Prince George districts. What proportion of these seedlings is in mixed plantings, or lost to poor survival, is not clear from available information, and bears future examination. It is estimated that about 10,000 hectares of Douglas-fir have been planted in the Prince George, Vanderhoof, and Fort St. James districts cumulatively in the last 10 to 12 years.

It should be noted that improvements in stock types, site preparation, stock handling, and identification of frost-prone sites make the prognosis for reliable survival and growth of Douglas-fir plantations much brighter than even a decade ago.

A strong trend in Douglas-fir types in the last five years has been the increase in retention of mature Douglas-fir reserves in cutblocks for visual objectives, seed, wildlife trees, and biodiversity requirements. Typically, Douglas-fir and hardwoods are the most popular choices. However, in general, in many cases fir leave trees have been left arbitrarily or haphazardly, with little thought to appropriate locations, windthrow hazard, or careful choice of leave trees. In many clearcuts with reserved fir, windthrow has been chronic, and sometimes severe, particularly on poorly-drained sites and compact tills with shallow rooting.

POTENTIAL DAMAGING AGENTS AND MITIGATION

In the northern SBS zone, Douglas-fir has two main damaging agents — wind and bark beetles. Unlike in the southern BC Interior and US, *Armillaria* and *Phellinus* root rots do not occur in this area. Some sites do have scattered pockets of *Tomentosus*, but Douglas-fir is moderately resistant.

Previous speakers have touched on the issue of windthrow management and leave-tree selection criteria. The Windthrow Handbook (Stathers *et al.* 1994) is an indispensable reference for this purpose. Essential to the task of field assessment is a short list of equipment and required actions. These include:

1. **A shovel** : DIG numerous soil pits and assess rooting depth. Remember, look for larger structural roots, not fine feeder roots, and regardless of observed roots, assess the general penetrability of the soil for root development. Are there obvious restricting layers and how deep are they?
2. **Your eyes**: LOOK for past evidence of blowdown, LOOK AT crown characteristics of potential leave trees, and LOOK FOR evidence of past stand development trends, fire scars on veterans, and so on that will help you assess how adapted individual candidate leave trees may be to conditions in a more open partially-cut stand.
3. **Your brain**:THINK about what you see ON SITE. Don't be overly beguiled by standardized guidelines. Remember that the Forest Practices Code REQUIRES your prescription to be SITE-SPECIFIC. Do not give this job to inexperienced junior field staff without adequate direct professional supervision and accountability. Prescribing leave-tree retention and partial cuts is <u>not</u> a job for rookies but needs a well-experienced eye and high level of professional experience.

Careful attention must be paid to leave-tree characteristics, and to soil, site, and general contributing factors to stand windthrow hazard as per Stathers *et al.* (1994). With the common occurrence of fine-textured, compacted glacial till soils and often restricted drainage on the sub-boreal plateau, it is recommended that pre-harvest windthrow hazard ratings and that leave-tree selection be significantly more conservative than practices developed from experience of stands growing on deeper soil types elsewhere. Figure 11 indicates some suggested minimum criteria for Douglas-fir leave trees in the SBS zone (adapted from past unpublished guides developed by John Revel and colleagues, and modified by data from current monitoring of windthrow in a range of partial-cuts).

In terms of bark beetle issues and control, there are extensive references and operational guidelines, most notably the Bark Beetle Guidebook (BC Ministry of Forests / BC Ministry of Environment, 1995). Much is made of the threat of fir bark beetle and potential impacts in fir stands, and much attention is focused on short-term control strategies. However, based on field observations over the last several years or so, discussions with various experts at this workshop, and observations on ensuing field trips, it appears that some fundamental assumptions about appropriate courses of action for long-term beetle management need to be examined.

Current bark beetle management in northern SBS fir stands focuses on prioritizing current infestation areas, salvage of mortality, and containment of green attack by a variety of technical methods. Salvage and containment are predicated largely on the removal of large "high-risk" diameter classes and mature age classes of Douglas-fir. In contrast, an ecosystem management approach examines the bark beetle dynamics and control measures in terms of Douglas-fir ecosystem characteristics, past patterns of natural disturbance, and stand development patterns. The goal is to address not just short-term stop-gap control issues, but long-term prevention strategies.

A fundamental, but poorly-understood issue relating to Douglas-fir beetle management is the issue of fire exclusion from Douglas-fir stands over the last half century or so. Fire exclusion has changed the stand structure, stocking, and dynamics of many fir stands to pre-dispose them to overstocking and attack by bark beetle. Extensive experience with fire-excluded stands in the southern interior and United States has strongly indicated that fire exclusion and resultant overstocking of stands by younger regeneration is a major agent of stress and subsequent bark beetle attack in such stands (Russ Graham, personal communication).

For example, at Battleship Bay on the north side of Stuart Lake near Fort St. James, the BC Ministry of Forests has been conducting trap tree programs, single-tree salvage, and small patch clearcutting over the last five years to attempt to contain bark beetle outbreaks in this sensitive recreation area. This site was visited during the field trip following this workshop.

The stand consists of two or several age classes — one, a well-distributed overstorey of larger Douglas-fir veterans of an estimated age of 150 to 300 years with prominent fire scars on the bark, and a second age class or age classes <80 years old. We would deduce from these observations that the stand has been subject to non-catastrophic stand renewing underburns in the past, but these have ceased with the advent of aggressive fire control. Observations of evidence of historical underburns in local fir stands is corroborated by other observations of fire scar occurrence on both Douglas-fir and lodgepole pine in the Pinchi-Tezzeron Lakes area north of Stuart Lake.

It is likely that the conventionally-accepted beetle "sanitation" approach of removing large diameter trees and leaving dense residual stands of smaller closed-canopied younger stems is moving the stand structure and stocking in a direction that is exactly <u>opposite</u> to past natural disturbance patterns and historical stand structure. It is recommended that what this stand needs to control bark beetle in the long run is a low thinning (thinning from below) under a shelterwood or irregular shelterwood prescription, substantial reduction in basal area density, and clearing out of a lot of the thickets of dense pole-sized trees in this stand. "Old-growth restoration" prescriptions in East Kootenay fir stands (Hawe and DeLong 1997) are taking a similar approach.

OUTLOOK FOR THE FUTURE AND RECOMMENDATIONS

General trends for SBS Douglas-fir forest types in the future are:

- increasingly detailed site-specific prescriptions for specialized objectives;
- more mixed-species prescriptions: coniferous and mixedwood (hardwood-conifer) mixtures;
- more operational trials of even-aged and some uneven-aged partial-cut prescriptions testing a range of residual stand densities;
- increasing emphasis on prescriptions that emulate the natural disturbance patterns and stand structures of historical Douglas-fir stands; and
- increasing emphasis on the neglected skill of tree-marking; this trend will include more professional input and detail in Douglas-fir prescriptions due to the specialized nature of ecosystems and need for detailed management.

An important point is that Douglas-fir types will need much more detailed and thoughtful intervention than silviculturists have become accustomed to in surrounding pine types. Douglas-fir types need more management input in the field to manage and sustain them.

RECOMMENDATIONS

We need to develop Douglas-fir silvicultural systems that maintain or restore natural stand attributes and disturbance regimes in stands that have been altered through past fire exclusion and selective high-grading. Retrospective stand reconstruction studies of historical and more recent patterns of Douglas-fir stand development on a range of sites should be a high priority throughout the northern range of fir.

The key concept for management of northern Douglas-fir is the need to be <u>site-specific</u>. At all costs we must avoid "cookie cutter" recommendations or dogmatic prescriptive approaches to management of Douglas-fir sites that are not sensitive to critical site-to-site differences in stand structure, site characteristics, windthrow susceptibility, stand management objectives, and higher-level plans. Poorly-designed, overly-general management guidelines will mislead the unthinking, and place unnecessary administrative obstacles in the path of the observant and innovative critical thinker.

It is important to manage and maintain a range of different stand structures on different sites to meet a range of objectives. Avoid overly simplistic guidelines or recommendations that do not recognize site-to-site differences in stand structure, species composition, stocking, or management objectives. Remember the old saying, *"Follow not the rule as a blind man follows the wall*!" For Douglas-fir management, use guidelines as just that — guidance — but follow the basic principle that prescriptions must be developed site-specifically, and preferably by the professional in the field, in order avoid such chronic over-simplification.

Based on the evidence to date, successful silvicultural management of Douglas-fir in the north is both possible and productive. Its management will be a challenge, but ultimately a rewarding one.

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EXPERIMENTAL PROJECT 660 - OVERVIEW OF THREE EXPERIMENTAL INSTALLATIONS - A 30-YEAR PROGRESS REPORT

DAVE COOPERSMITH, MARIAN MCLELLAN AND JOHN STORK

Experimental Project 660 (EP 660) was established in 1967 to evaluate and compare the performance of plantations of white spruce, lodgepole pine and Douglas-fir at various espacements on three different plantations within the Prince George Forest Region. This report provides an overview of the history, rationale and methodology of the study.

Details on the results of the 30-year growth performance of the three individual study locations are reported in separate Research Note publications within this series: Research Note PG 12-1 for the Buckhorn Ridge Installation, PG 12-2 for the Bobtail Road Installation, and PG 12-3 for the Chilco Creek Installation.

FORWARD

The long periods of time required to grow a stand of trees from initial planting to final harvest is a unique aspect of the practice of forestry. Periods of time of five to ten years, which may encompass the entire lifetime of a scientific study in other disciplines, mean few long-term studies exist on plantation growth and yield.

The EP 660 project provides some unique insights into the growth patterns and the interactions occurring within a forest plantation over 30 years. To our knowledge, this is one of the very few studies of its kind in the Prince George area that has been continually monitored over such a period of time.

In reading through the project reports, we often overlook the history surrounding projects of this nature and the commitment of the researchers who pushed to install and maintain these study plots. The first research plantations on the Buckhorn Ridge were installed by T. Decie in 1957, then Forester-in-Charge at the Aleza Lake Experimental Station northeast of Prince George. The original white spruce and Douglas-fir stands were logged in 1954/55. Parts of the present research area were burned in the small Buck Fire of 1957. In 1958, the first spruce espacement trial in the central interior of the province was established on the site (EP 549). This plantation was subsequently wiped out by the huge Grove fire in August 1961. The trial was re-established as the EP 660 near the original site in the summer of 1967. In 1965 John Revel and Harry Coates re-established the spruce espacement trials on the Buckhorn site. A new study, designated EP 660, was established in 1967 at the Buckhorn site following the design criteria of EP 549. Two installations were added to the EP 660 project: a second installation at Cluculz Lake on the Bobtail Forest Road east of Prince George, and a third installation near Chilco Creek northeast of Vanderhoof.

INTRODUCTION

Despite the huge size of the Prince George Forest Region, planting stock for reforestation work is drawn from a relatively small number of species. Only two species of conifer are planted in significant number in the Prince George region. Lodgepole pine (*Pinus contorta*) and Engelmann and white spruce (*Picea engelmannii* x *Picea glauca*) account for more than 97.5% of all the trees planted within the region (BC Ministry of Forests, 1995). Douglas-fir (*Pseudotsuga menziesii*) makes up less than 3% of the total planting program. It has been shown to have been a poor early plantation performer in artificially regenerated stands.

In northern BC, selecting the appropriate tree species and stocking level to ensure optimum growth and yield is still the most important silvicultural decision affecting the yield of managed stands. Species selection and the initial espacement of planted trees has a significant effect on the growth and yield of the stands, on wood quality, and on planting and stand management costs (Bella and DeFrancheschi 1974).

Unfortunately, very little data are available on the long-term growth and yield of various species, planted at a variety of stand densities, and on sites of different quality in the central interior of BC. More knowledge is needed to assist foresters and silviculturalists is managing these stands for optimum productivity. For example, there is little information on which to base estimates of volume losses to various disease and animal pests. Future stocking standards pertaining to species selection must reflect the probability of such losses over the entire rotation of the stand, not simply to the end of the free-growing period.

STUDY OBJECTIVES

There are three primary objectives for EP 660:

1. To establish pure, replicated plantings of Douglas-fir, lodgepole pine, and white spruce at 2 m x 2 m, 3 m x 3 m and 4 m x 4 m espacements.
2. To monitor these plots with periodic evaluations of survival, incidence of damage and disease, and growth and yield for each species-espacement combination.
3. To maintain each installation of the project as a long-term demonstration and teaching area.

STUDY AREAS

The three study locations within the Prince George Forest Region were chosen for this experimental project because they represented a range of soil conditions with similar logging histories.

THE BUCKHORN RIDGE SITE

The Buckhorn Ridge research site is located approximately 45 kmsoutheast of Prince George along the Buckhorn Forest Service Road (Figure 1). The site lies within the sub-mesic to mesic association of the Fraser Basin variant of the Moist Cool Central sub-zone of the Sub-Boreal Spruce biogeoclimatic zone (SBSmk1/05, formerly the SBSe2/05, DeLong and Tanner 1996). Mean elevation of the study area is approximately 900 m.

The Buckhorn area is underlain by Brunisolic Gray Luvisols developed from medium to moderately-fine textured, gravelly glacial till parent material (Dawson 1989). This area, along with much of the Fraser River basin, has a root-restricting compacted Bt horizon at approximately 30 cm depth in the soil profile. Frequent fires in the Buckhorn area have removed much of the organic layer more typically found under mature forest stands in and around Prince George. A very thin, poorly developed Mor forest floor is present under most of the juvenile stands on this site.

THE BOBTAIL ROAD SITE

The Bobtail study site is located approximately 60 km southwest of Prince George, at kilometre 21 along the Bobtail Lake Forest Service Road. The site is located within the sub-mesic to mesic wild sarsaparilla - princes pine - sitka alder association of the Nechako River variant of the Dry Warm Southern sub-zone of the Sub-Boreal Spruce biogeoclimatic zone (the SBSdw3/04.1, formerly the SBSk3/04.1, DeLong *et al*, 1993). Mean elevation of the study area is approximately 840 m.

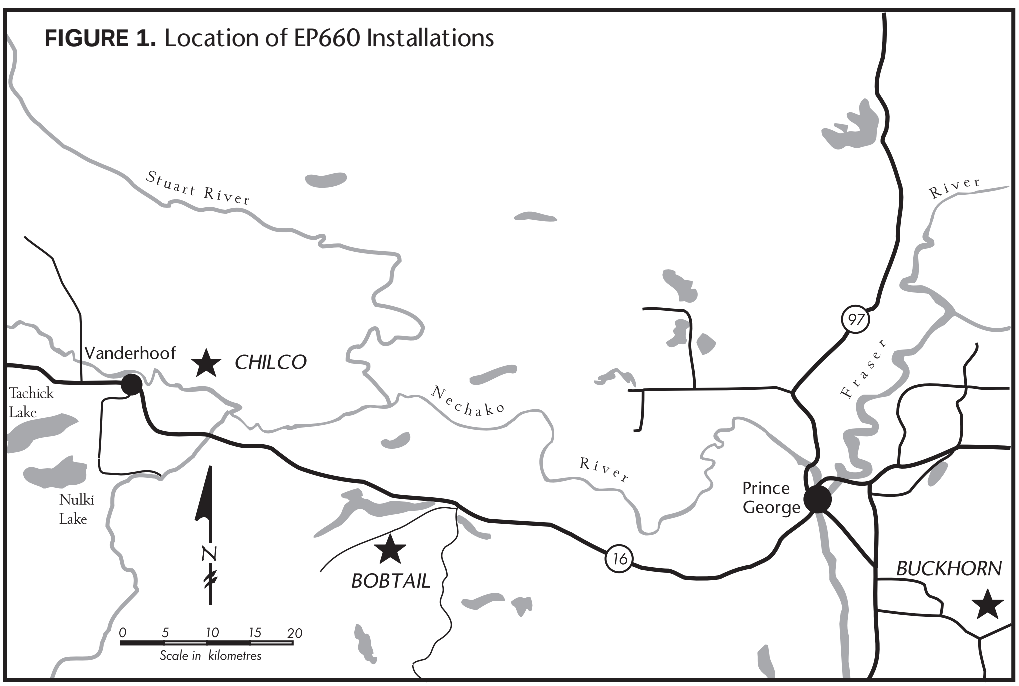
The soils of this area are brunisolic gray luvisols belonging to the Deserters series (Dawson1989). These soils are developed from gravely and stony glacial till deposits and tend to be medium to moderately fine textured gravely loams to gravely clay loams.

The original stands of white spruce were clearcut logged in the winter of 1964-65, and the cut blocks were broadcast burned in 1965.

THE CHILCO CREEK SITE

The Chilco Creek study area is located approximately 65 km northwest of Prince George and 20 km east of Vanderhoof along the River Road. Like the Cluculz Lake study site, the Chilco Creek installation is located within the SBSdw3. However, the Chilco site is moister than the Bobtail installation and is located in the mesic to sub-hygic black twinberry - colt's foot association (SBSdw3/06, formerly the SBSk3/06, DeLong,

FIGURE 1. Location of EP660 Installations



et al, 1993). The mean elevation is approximately 760 metres. The original stands of white spruce were clear-cut logged in 1965/66, and the site was broadcast burned in 1966.

The soils of the Chilco Creek area are Orthic Gray Luvisols from the Pineview and Vanderhoof soil series (Dawson 1989). These soils have developed from clayey glacial lake deposits over glacial till and tend to be very fine textured clays and silty clays.

MATERIALS AND METHODS

PLANTING STOCK

Seedlings utilized in the species-espacement trial were grown from local provenances of lodgepole pine, Douglas-fir, and white spruce seed. The seedlings were either 1+1 (lodgepole pine and Douglas-fir) or 2+1 (white spruce) bare-root transplants. The 2+1 white spruce stock was utilized to approximate the size and shoot-to-root ratio of the larger 1+1 lodgepole pine and Douglas-fir seedlings.

PLOT LAYOUT

Initial planting at the three sites was carried out in May, 1967. First year mortality was replaced in April of the following year. Lower than expected first year mortality resulted in surplus planting stock, which was subsequently utilized for a fourth espacement of each species in the southwestern corner of the Buckhorn Ridge site only. These additional plots, planted at 1.5 m x 1.5 m espacement, were installed in the spring of 1968. This treatment was not replicated at any of the other installations.

Experimental plots were planted as either 11 x 11 tree plots (for the 3 m x 3 m and 4 m x 4 m espacements), 14 x 14 tree plots (for the 2 m x 2 m espacements) or 18 x 18 tree plots (for the 1.5 m x 1.5 m espacements). Evaluation on each of the replicate plots was limited to the centre 49 trees, however, to reduce the effect of plot edges on measured variables.

PLOT MAINTENANCE AND STAND MEASUREMENT

The plot boundaries, trail flagging, plot identity tags and tree number tags established in 1967 have been maintained as required. However, there was no concerted effort to brush and weed the installations until 1979. Complete brushing and weeding of plots and boundaries took place in 1979, 1983, 1986 and 1996 at the Buckhorn and Bobtail sites, and in 1976, 1986 and 1997 at the Chilco site.

Since their establishment in 1967, the three study area plots of EP 660 have been evaluated on five occasions: an 11-year evaluation in 1977, a 15-year evaluation in 1981, a 20-year evaluation in 1986, and a 25-year measurement in 1991. The 30-year evaluations, discussed in this Research Note, were completed in the Fall of 1996 and spring of 1997.

During the first measurements in 1977, the trees were not numbered. In 1981, the study trees were tagged, but many of these original tags were lost or destroyed. All trees within the plots were re-tagged in 1986. However, the pattern of live and dead trees within plots dating back to 1977 does allow us to identify individual trees from early measurements. All evaluations and analyses were based on plot means which were unbiased by the inconsistent numbering.

Up to 1991, measurements of tree heights were made to the nearest 5 cm using 15 m telescoping height poles. After 1991, all height measurements were made to the nearest 10 cm, using a Criterion laser.

Trees were measured for diameter at breast height (DBH) and estimates made of the height to live crown, greatest crown width and least crown width. The diameter of the lowest live branch was measured. Damage to stems, foliage and leaders from small mammals, disease and abiotic factors was noted. Qualitative estimates of the damage severity from each source were based on the extent of the injury (for example, the amount of the stem girdled by a squirrel or hare) and the apparent health of the attacked tree in question.

EXPERIMENTAL DESIGN

Two replicates of each of the species-espacement combinations were laid out in side-by-side rectangular blocks measuring approximately 320 m by 42 m. Plot assignments were freshly randomized for each of the two replicates at each site, resulting in a randomized complete block experimental design. The data were analysed by a repeated measures Analysis of Variance (ANOVA) technique.

RESULTS AND DISCUSSION

The results for each of the three individual EP 660 trials are reported in accompanying Research Note publications PG 12-1: The Buckhorn Ridge Research Site; PG 12-2: The Bobtail Road Research Site; and PG 12-3: The Chilco Creek Research Site. Some notable observations that are common to all three research installations.

- The lodgepole pine surviving the 30 years since the EP 660 trials were established are still doing well. They are still the tallest and largest diameter trees at all three installations. However, there has been heavy damage from biotic sources (disease, insects and small mammals) during this time. These losses have resulted in poorly stocked stands, and losses to total volume (in these stands).
- Douglas-fir has grown well on all three sites. The Douglas-fir has suffered very little biotic damage. However, this species has been very susceptible to abiotic damage (hail, snow load, frost, etc.)
- White spruce is the tortoise in the race. It started slowly and, after 30 years, is still substantially shorter and smaller in diameter than either lodgepole pine or Douglas-fir. However, the growth rate of this species is now

picking up and it also appears to be immune to most biotic and abiotic damage that has so badly impacted the plantations of pine and Douglas-fir.

CONCLUSIONS

Douglas-fir is an extremely valuable species that can grow very well on the right sites in the Prince George area. However, it is susceptible to abiotic damage such as frost (in younger plantations), hail and snow break. Tree breeding programs in other regions have tried to produce Douglas-fir trees with low branch angles that will catch smaller amounts of snow, making them less susceptible to breakage. Unfortunately, there appears to be little opportunity to select for greater frost resistance in this species, given that we are so close to the northern limits of its distribution.

Douglas-fir does not commonly occur in pure stands in nature, so some thought should be given to growing it as one species in a mixedwood complex. Such stands probably offer individual Douglas-fir much better protection from abiotic damage than would the single species plantings such as those at the EP 660 installations.

Lodgepole pine shows excellent resistance to most abiotic agents. However a host of biotic pests afflicts this species. Plantations that start at relatively low total densities may have very few live trees left after one or two outbreaks of cyclical pests such as squirrels or snowshoe hares (Sullivan 1987, 1996, Sullivan *et al.* 1981, 1987, 1996) or from the losses to endemic pests such as western gall rust (Hendry and Cozens, 1989; Van der Kamp, 1981). Wood quality in future stands grown at low density is also a subject that deserves a great deal of additional study. All the lodgepole pine grown at low density and wide espacements had very large lowest live branch diameters. Large live branches on the first log has been shown to negatively impact both future wood quality and wood recovery rates (Middletown *et al.* 1995, 1996).

Although white spruce has grown much slower than either Douglas-fir or lodgepole pine at the EP 660 installations, many of the spruce stands now contain some very impressive trees. White spruce seems to be less susceptible to many of the pests, pathogens and abiotic damaging events that have plagued both Douglas-fir and lodgepole pine. This species has grown slowly but steadily for the past 30 years, and the species differences in height and diameter between it and the other two species are not as evident now as they were just 10 years ago. It may well be that in 30 or 40 years these spruce stands will have the greatest overall wood value.

The data gathered to date present some useful insights into the early to mid-successional progress of the three species. However, the story of these stands has changed substantially in the last 10 years and will likely change again. It is still too early to make conclusions about the long term outcome for these stands.

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EXPERIMENTAL PROJECT 660 - A 30-YEAR PROGRESS REPORT: BUCKHORN INSTALLATION

DAVE COOPERSMITH, MARIAN MCLELLAN AND JOHN STORK

The Experimental Project 660 (EP 660) is a long term forest research study examining the influence of planting density on the growth performance of white spruce, Douglas-fir and lodgepole pine.

The Buckhorn Ridge study area is one of three EP 660 installations in the region surrounding Prince George. The three study areas were created at the same time, using the same study method and evaluation procedures. Details on the EP 660 study rationale and methodology are reported in Research Note PG 12 — "Experimental Project 660: Overview of Three Experimental Installations," available in this publication series.

This Research Note reports the results for the first 30 years of monitoring at the Buckhorn Ridge research site. Results from the two companion studies are also reported in this series as Research Note PG 12-2 "Experimental Project 660 — Bobtail Road Installation: 30 Year Progress Report" and Research Note and PG 12-3 "Experimental Project 660 — Chilco Creek Installation: 30 Year Progress Report."

THE BUCKHORN RIDGE STUDY SITE

The Buckhorn Ridge research site is located approximately 45 km southeast of Prince George along the Buckhorn Forest Service Road. The site is located within the sub-mesic to mesic association of the Fraser Basin variant of the Moist Cool Central sub-zone of the Sub-Boreal Spruce biogeoclimatic zone (SBS mk1-05, DeLong and Tanner, 1996) Mean elevation of the study area is approximately 900 m.

The Buckhorn area is underlain by brunisolic gray luvisols developed from medium to moderately-fine textured, gravelly glacial till parent material (Dawson 1989). This area, along with much of the Fraser River Basin, has a root-restricting compacted Bt horizon at approximately 30 cm depth in the soil profile. The soil on the ridge itself are shallow, with outcroppings of bedrock exposed at various places within the plot. Frequent fires in the Buckhorn area have removed much of the organic layer more typically found under mature forest stands in and around Prince George. A very thin, poorly developed Mor forest floor is present under most of the juvenile stands on this site.

The original white spruce and Douglas-fir stands were logged in 1954/55. Parts of the present research area were burned in the small Buck fire of 1957. In 1958, the first spruce espacement trial in the central interior of the province was established on the site (EP 549), which was later wiped out by the huge Grove fire in August 1961. The trial was re-established near the original site in the summer of 1967, and expanded to include lodgepole pine and Douglas-fir. It became known as the EP 660 study.

The Buckhorn Ridge area has been a prime area of interest for research scientists and operational silviculturalists. More than 12 research trials have been established there, including three direct seeding trials, bullet container planting trials performed by the Canadian Forest Service, pine thinning and fertilization research, and lodgepole pine gall rust pathological studies.

RESULTS AND DISCUSSION

HEIGHT AND DIAMETER GROWTH

The stands at Buckhorn Ridge are changing rapidly. In the highest density (closest espacement) lodgepole pine and Douglas-fir stands, the crowns of the trees have closed and are starting to lift. This indicates that these stands now fully occupy the site and

FIGURE 1. Mean stand heights for the three species x four espacements combinations at the Buckhorn Ridge installation. Plotted values represent the means of two combined 49-tree replicates for each species-espacement combination.

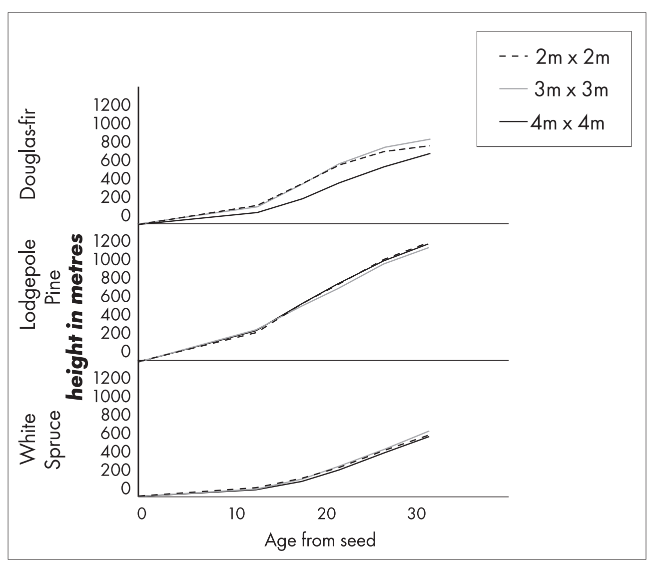
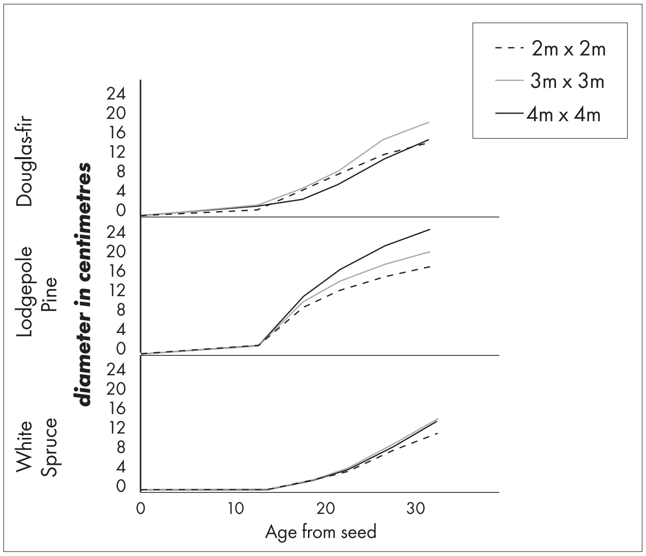


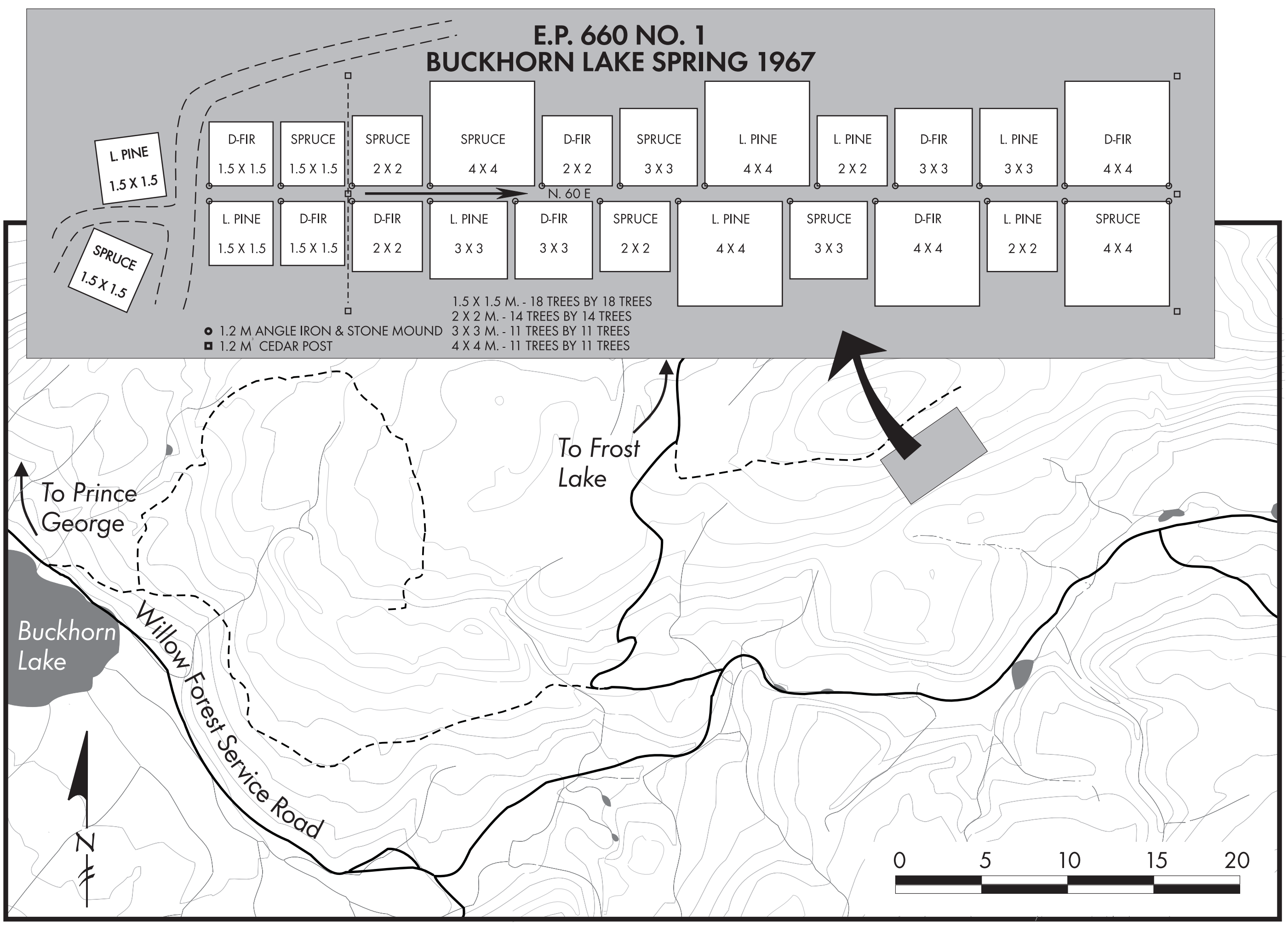
FIGURE 2. Mean stand diameter dynamics for the three species x four espacements combinations at the Buckhorn Ridge installation. Plotted values represent the means of two combined 49-tree replicates for each species-espacement combination.



that competitive interactions between trees are intensifying. The more narrow crown form and greater shade tolerance of white spruce means that the crown of these trees have not yet started to lift.

Clear and statistically significant species differences are evident in the height growth of the three species. Lodgepole pine is the tallest species, at an average height of approximately 11.4 m, followed by Douglas-fir at approximately 7.8 m average height and white spruce at approximately 5.9 m (Figure 1). Both lodgepole pine and Douglas-fir have grown very well on the warm, well-drained soils of this site.

The initial growth rate of white spruce has been quite slow relative to the other two species. This is not surprising, since the south-western aspect and sub-mesic nature of this site would not be favourable to spruce growth. Slow initial growth of bare-root spruce stock types was also typical for the time, leading to the early abandonment of this stock type in favour of container-grown seedlings. However, the spruce are now growing well, as much of the competing alder and willow has died back, and many individual spruce trees are as tall or taller than their neighbouring Douglas-fir and lodgepole pine. The spruce have also suffered much less damage in recent years compared to the lodgepole pine and Douglas-fir.



Although less clear than for the species effect, espacement did have a significant effect on height growth, and appears to have had a lesser effect on diameter growth. There was no difference between the 2 m and 3 m espacements. Trees planted at the widest (4 m) espacements were the shortest for this installation. The species trend towards taller trees at closer espacements was most evident in Douglas-fir, followed by lodgepole pine. White spruce showed the least evidence of increasing tree heights with closer spacings.

As would be expected, trees at closer espacements tended to have smaller diameters (Figure 2). This was most evident in lodgepole pine where the trees in the widest espacement were largest, while those in the closest espacement were smallest. These trends were much less clear in Douglas-fir and white spruce.

VOLUME AND BASAL AREA DEVELOPMENT

Volume and basal area estimates were produced from height and diameter data utilizing equations for juvenile plantations from Kovats (1977). Similar trends to those observed in height and diameter growth were also seen in basal area and volume development. There are clear differences between the three species at Buckhorn, with lodgepole pine having the greatest volume and basal areas at a given espacement, followed by Douglas-fir and white spruce (Figures 3 and 4). Basal area is now near ›32 m^2/ha for the closest espacements of lodgepole pine, and nearly 30 m^2/ ha for the equivalent espacement of Douglas-fir. The widest 4 m x 4 m espacement of lodgepole pine has only 60.1% of the total basal area of the closest 2 m x 2 m espacement. For Douglas-fir, the (4 m x 4 m) treatment contains only 27.6% of basal are of the 2 m x 2 m treatment. White spruce is well below the basal areas of both Douglas-fir and lodgepole pine, with the best-stocked spruce stand now at approximately 25 m^2/ha basal area.

Total volumes are now developing rapidly in most stands at Buckhorn. The highest volumes of pine and Douglas-fir are again found in the closest espacement, where volumes for lodgepole pine are nearing 145 m^3/ha. The equivalent volume for Douglas-fir is approximately 64 m^3/ha. White spruce has again lagged far behind both lodgepole pine and Douglas-fir. Maximum volumes in white spruce are approximately 31 m^3/ha.

These data reinforce the well-known silvicultural observation that changes in stand density have greater effect on stem diameter than on tree height (Perry 1985). These data also demonstrate that shade intolerant species such as lodgepole pine tend to show these espacement effects sooner than more shade tolerant species such as Douglas-fir and white spruce. In some cases, going to wider espacements will result in basal areas and total volumes that are less than 25% of those achievable at higher planting densities. It must be remembered, however, that these calculations are for total rather than merchantable volumes. Differences in volumes tend to be less between high density and low density stands where merchantable volume rather than total volumes are calculated (Pollack *et al.* 1992).

FIGURE 3. Mean stand total volumes for the three species x four espacements combinations at the Buckhorn Ridge installation. Plotted values represent the means of two combined 49-tree replicates for each species-espacement combination.

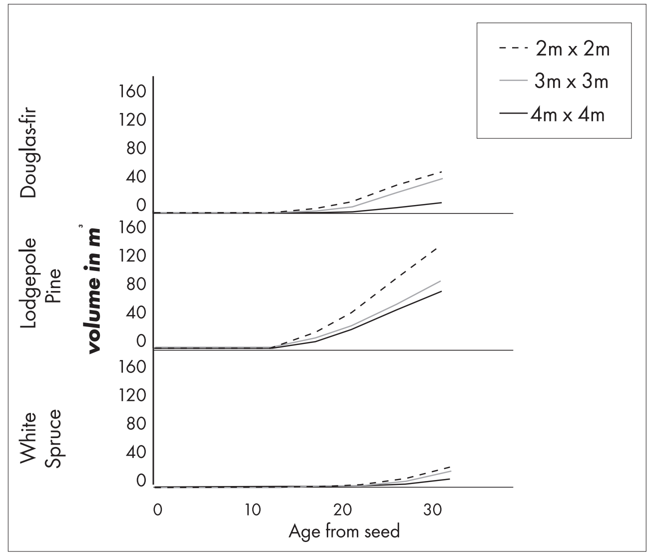
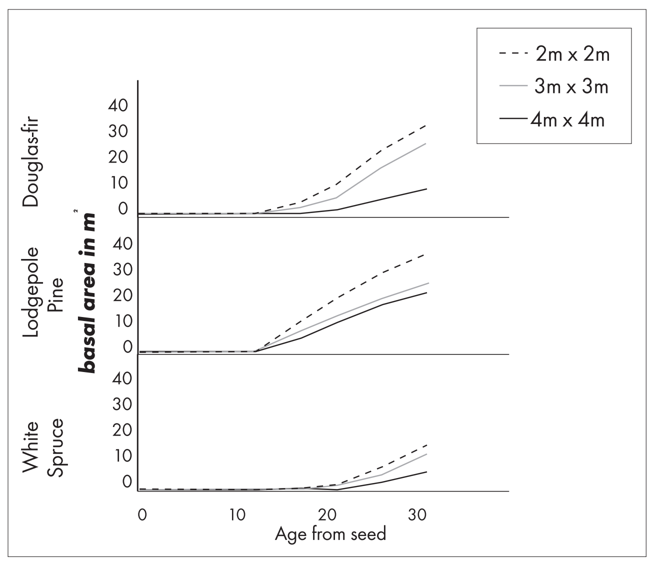


FIGURE 4. Mean stand basal areas for the three species x four espacements combinations at the Buckhorn Ridge installation. Plotted values represent the means of two combined 49-tree replicates for each species-espacement combination.



Middleton *et al.* (1995) have found that production of premium structural and appearance grades of lumber were optimum at approximately 1100 stems/ha of lodgepole pine at final rotation (95 years) on good sites. Moving to densities that were either higher lower from the 1100 stems per hectare optimum at final rotation resulted in significantly higher levels of poor quality lumber recovery. At densities higher than the optimum, average tree diameter was too small to optimize high quality timber recovery. At lower densities, poor self pruning resulted in large numbers of knots and large percentages of juvenile wood which also lowered quality wood recovery. This would suggest that initial planting densities should be much greater than current levels if significant plantation losses are expected.

INCIDENCE OF DISEASES, PESTS AND ABIOTIC DAMAGE

Data for diseases, pests and pathogens have been summarized for the 1986 and 1996 measurement only (Table 1). Significant abiotic damage has occurred since 1986, especially to Douglas-fir.

INCIDENCE OF DISEASES

Of the three species planted in the EP 660 trial, lodgepole pine has had by far the most disease and insect pest problems. The most common pathogen influencing lodgepole pine has been Western gall rust (*Endocronartium harkenssii*) which has infected most of the lodgepole pine.

The infection levels of Western gall rust evident at the 20-year evaluation appear to have increased from the 15-year assessment, and there are greater levels of branch infection at wider planting espacements. There was a dramatic decrease in the number of stem galls noted between the two evaluations. This is because many of the trees with prominent stem galls in 1981 would have died by 1986. The stem and branch gall infection estimates were made on live trees only. Second, a tree with multiple stem problems (stem galls and bark peeling by small mammals) would probably be noted by only the more serious injury. These two factors probably account for the large decrease in noted stem galls between the two evaluations, and the low number of stem galls in general.

In addition to the western gall rust infections, the lodgepole pine stands also contained minor amounts of Atropellis canker (*Atropellis piniphila*) and stalactiform blister rust (*Cronartium coleo-sporioides*) infection.

INSECTS

Numerous insect pests infest the stands of the three installations including the spruce leader weevil (*Pissodes strobi*), the spruce gall aphid *(Adelgies cooleyi*), the lodgepole pine leader weevil (*Pissodes terminalis*) and Warren's root collar weevil (*Hylobius warreni*).

There are moderate endemic levels of spruce leader weevil on the white spruce , while virtually every spruce in the plantation has been attacked to some degree by spruce gall aphid. These pests are probably causing some height growth losses and are responsible for form defects within these stands. The damage from the terminal weevils was much less severe in the lodgepole pine than in white spruce.

ANIMALS

The most serious pest problem evident in the EP 660 stands has been cambial feeding on lodgepole pine by red squirrels (*Tamiasciurus hudsonicus*) and snowshoe hares (*Lepus americanus*). Animal damage to white spruce or Douglas-fir has been rare. Only a few examples of hare and squirrel stem damage

TABLE 1. Summary of the percentage of stems within the Buckhorn plantations that showed snowshoe hare (hares) and red squirrel (squirrel) damage and were dead or broken topped by the 1986 evaluation. Data for each species-espacement combination are for all trees, both live (trees with visible bark peeling) and dead (where cause of death could be ascribed with certainty to snowshoe hares or squirrels). Species codes: Sw = white spruce, Pl = lodgepole pine, Fd = Douglas-fir.

Damage Caused		Species	Plantation Espacement (m)			
			2.0 x 2.0	3.0 x 3.0	4.0 x 4.0	Species Average
hares	1981	Pl	22.4	24.5	19.4	24.2
	1986	Pl	39.0	8.0	24.0	25.6
	1986	Sw	0	0	0	0
	1986	Fd	0	0	0	0
squirrel	1996	Pl	56.1	61.2	53.1	48.2
	1996	Sw	0	0	0	0
	1996	Fd	0	0	0	0
dead	1996	Pl	20.4	18.4	18.4	19.1
	1996	Sw	17.3	18.4	25.5	13.6
	1996	Fd	1.0	6.1	19.4	6.6
damaged tops	1996	Pl	15.4	12.5	23.4	14.6
	1996	Sw	33.3	41.3	50.7	40.6
	1996	Fd	52.6	64.1	63.3	52.7

have been observed on these species, along with some minor ungulate browsing to the leaders and branches of both species.

Most of the snowshoe hare damage to lodgepole pine occurred in the earlier years of plantation establishment, when stem diameters were still quite small. Up to and including the 1981 evaluation, damage to pine stems by snowshoe hares was viewed as the most serious pest problem in the EP 660 plots. However, little new hare damage to the larger pine stems has been observed in the most recent measurements.

Unlike the snowshoe hares, red squirrels prefer larger diameter pine trees. Red squirrel feeding damage is now the most common injury in the pine plantations. The squirrels have concentrated their feeding on the most vigorous pine stems in the plots, establishing a feeding area around a central tree. Within these feeding areas, heavy scarring damage has been recorded. Many of the attacked trees have been nearly girdled, and they are likely to die in the future as a results of these attacks. Even small wounds may act as entry courts for future disease infections.

It is likely that the small plot size of the EP 660 installations, surrounded as they are by extensive areas of unthinned natural pine stands, attract large numbers of squirrels and results in higher than expected damage levels. Sullivan *et al.* (1996) found an inverse relationship between stand density and squirrel damage in lodgepole pine stands throughout the interior of BC. Low density stands do not offer squirrels as much cover as high density stands, so it would appear that the squirrels are preyed on more heavily in thinned areas, especially by hawks and owls. Higher predation on the squirrels leads to less damage in pine. By contrast the EP 660 stands have lots of dense pine stands surrounding them, offering the squirrels ample shelter from predators.

ABIOTIC DAMAGE

Since 1991, abiotic events have had the greatest impact on the stands at all three EP 660 sites. During the 1986 evaluation, Douglas-fir appeared to be rapidly catching up to lodgepole pine in both total height and average diameter, and researchers expected that the Douglas-fir would be as large or larger than the pine in most plots by the 1991 evaluation. This has not happened.

Since 1989, a series of extreme weather events have affected the EP 660 stands. The Douglas-fir were damaged more than the other two species. During an early-January arctic outbreak event in 1989, the sudden drop in temperature resulted in dead top buds and top dieback for most of the Douglas-fir and large amounts of spruce. An early spring hail storm in 1991 also resulted in dead and broken tops throughout many of the EP 660 plantations. Again, the damage has been heavier in Douglas-fir than in the other two species.

The extent of top damage in the Douglas-fir stands at the Buckhorn site is surprising for several reasons. The Buckhorn site slopes dramatically to the southwest. It sheds cold air quite well. Yet it would appear that the Douglas-fir at Buckhorn have been repeatedly damaged by frost events. It is possible that the provenance of seed used at the Buckhorn trial was particularly susceptible to frost damage, or that it is "off-site" at Buckhorn. None of the Douglas-fir naturals in the surrounding stands shows the same level of damage as do the Douglas-fir plantations at the Buckhorn site of EP660.

The net result of these events has been that most of the Douglas-fir have lost five to seven years of top growth. These losses have undoubtedly affected the Douglas-fir average top height data. Indeed, an examination of the graphs of Douglas-fir and lodgepole pine average diameter growth shows that Douglas-fir is now as large or larger in diameter than equivalent lodgepole pine at similar espacements. This is also clear if we examine the graphs for basal area. Unlike volume calculations, basal area is not affected by top height. There is little difference between the two species in terms of site occupancy.

The tallest undamaged individuals of both species are now ›14 metres tall. Had the Douglas-fir managed to escape these devastating abiotic events, it would likely be the leading species in terms of both volume, height and diameter at Buckhorn ridge now.

As a final note, it does not appear that the abiotic damage is finished in the Douglas-fir plots. Many of the Douglas-fir now have a very flat topped appearance. Because of this, they catch much greater amounts of snow, making them very susceptible to snow breakage. When we visited the Buckhorn site in early December of 1996 following a heavy snowfall, we noticed several newly broken Douglas-fir in the plots.

CONCLUSIONS

- Although probably greater than would be observed operationally, the levels of damage observed in the lodgepole pine espacements at Buckhorn are alarming. Where cyclical pests (hares and squirrels) and endemic diseases are prevalent, initial establishment densities will have to be higher in order to achieve wood quality objectives at final rotation. A target density of 1100 stems/ ha at final rotation would appear to be a reasonable goal.
- Douglas-fir shows very good growth potential on some sites in the SBSmk. It is prone to much less damage from biotic sources. Douglas-fir rarely grows in pure stands in nature, and is moderately shade-tolerant in the SBS. Planting Douglas-fir in a mixture, either with other conifers or with a broadleaf species such as paper birch, may afford this species greater protection from abiotic events.
- Particular attention should be paid to said provence if Douglas-fir is to be utilized. Selecting provence with a high resistance to frost damage is a necessity in the SBS.
- White spruce has lagged behind both Douglas-fir and lodgepole pine in terms of height and diameter growth since the first evaluation at Buckhorn in 1977. Much of this poor initial growth can be accounted for by the poor

initial growth performance of the 1967 bare-root stock. Current container-grown types perform much better after outplanting than do their earlier bare-root cousins. The long-term resistance of white spruce to abiotic and biotic damage events (in particular the rusts that plague many pine plantations) may outweigh the slower initial growth that this species has shown.

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EXPERIMENTAL PROJECT 660 - A 30-YEAR PROGRESS REPORT: BOBTAIL ROAD INSTALLATION

DAVE COOPERSMITH, BRUCE ROGERS AND VERA SIT

INTRODUCTION

Which tree species to plant following harvest and the density of planting are fundamental choices by foresters at the beginning of a rotation. These choices will influence not only the future options available to foresters, but also many of the final outcomes at subsequent harvest. They are also the two factors most easily controlled by the forester (Daniel *et al.* 1979).

Plantation density is known to have the greatest initial effect on mean tree size (quadratic mean diameter or QMD, also known as average stand diameter) and subsequently, if densities are high enough, on final yield at rotation (Daniel *et al.* 1979). However, density also strongly affects the height of the live crown. Stands grown at high density have live crowns concentrated in their upper boles. This results in trees with less taper and greater proportions of mature wood to juvenile wood when compared to trees grown at lower densities. It is rare in the Prince George region for target stocking densities to go above 1200 stems per hectare (sph) (Anonymous 1993). Stands that are grown at densities of 1200 sph and lower usually have very large live crowns, maintain live branches for long periods of time on the lower bole and have large branch diameters. Daniet *et al.* (1979) have noted that large branch diameter is one of the major causes of degrade in lumber produced from second-growth stands. It is also the one stand characteristic that can be controlled at planting or manipulated through silvicultural treatments.

PHOTOS 1 & 2: Lodgepole pine can live for many years with stem galls of western gall rust. However, eventually the weakened stems will snap due to wind or snow loading, as has this 31 year old lodgepole pine.

Relative to other areas of British Columbia with more southern or coastal climates, foresters working in boreal and sub-boreal forests of north-central BC have relatively few species of conifers to choose from. More than 97.4% of all the planting within the Prince George Region is accomplished with only two species: interior white spruce (*Picea glauca* [Moench] Voss) and lodgepole pine (*Pinus contorta* Doug. *ex.* Loud.) (Anonymous 1997). Together, these two species represent only 74.16% of the volume of billed stumpage within the region. Other species such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), sub-alpine fir (*Abies lasiocarpa* [Hook.] Nutt.), western redcedar (*Thuja plicata* Donn *ex* D. Don in Lamb.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) are under-represented in the numbers of seedlings replanted versus their billed volumes. We can interpret these data as indicative of a bias towards species which are known to have very fast initial growth following out-planting. Tree species that lack fast initial growth — those which have real or perceived problems at establishment with frost and other abiotic site factors, or those species which are utilised so seldom that little operational experience in growing or planting them exists — have traditionally been avoided in the Prince George Region.

The bias towards fast initial height growth is understandable. In BC silviculture prescriptions must specify time lines for stands to reach a "free growing" condition following harvesting. A free growing stand is defined as "a stand of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees" (Anonymous 1995). Species with slower initial height growth will take longer to reach the minimum heights necessary to be declared free growing, or may require additional silvicultural treatments to reach free growing.

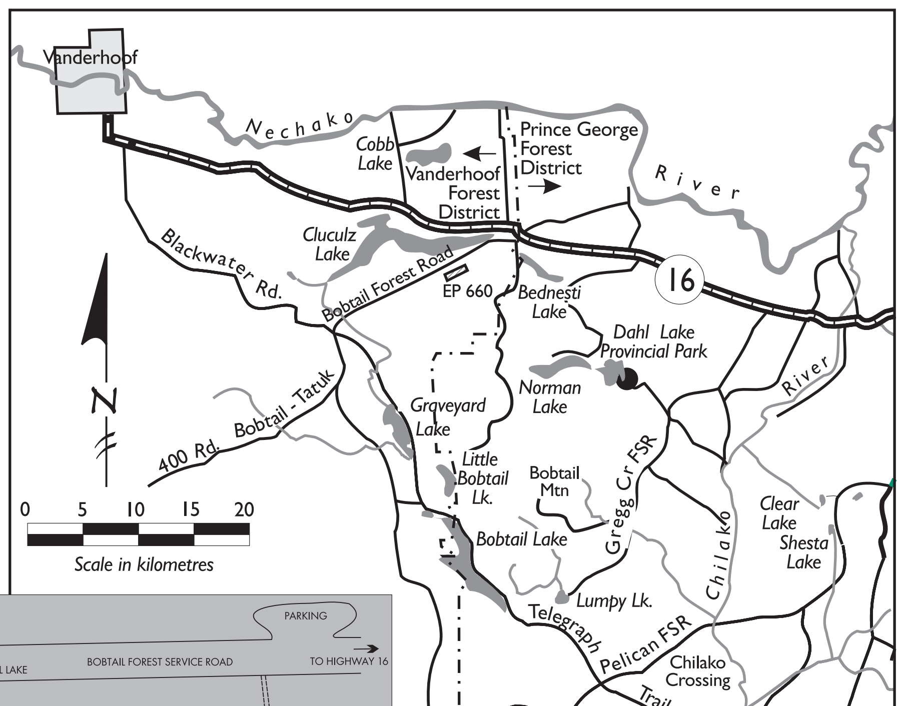
This bias toward tree species that display fast initial growth may have unforeseen consequences. While species such as lodgepole pine do display fast initial growth, the differences in overall growth rate between fast initial growth species and those species of slower initial growth often decrease with time (Bella and De Franceschi 1974). Species which display very fast initial growth also tend to be highly susceptible to pest and pathogen problems (e.g. red squirrel [Sullivan *et al. 1996]* and western gall rust [Van der Kamp 1981] damage to young lodgepole pine stands). Very often these agents damage trees well past the age that free growing is declared (photos 1 & 2). Other species may indeed have slower initial growth, but offer much greater resistance to pests and pathogens. Over the course of a rotation it may be that resistance to a wide range of pests, pathogens and abiotic damage is much more important for the achievement of management objects than is initial growth rate.

EP 660 is a long-term plantation study examining the influence of planting density (espacement) on the growth performance of white spruce, Douglas-fir and lodgepole pine. Established in 1967, this study is one of the oldest plantation studies in northern BC.

The Bobtail Road study area is one of three EP 660 installations surrounding Prince George. These three study installations were created at the same time using the same experimental methodology and planting stocks. Details on the EP 660 study rationale and methodology are reported in Research Note PG-12 (Coopersmith *et al.* 1997a). Results from the Buckhorn Ridge trial are summarized in Research Note PG-12-1 (Coopersmith *et al.* 1997b), while those for the Chilco Creek installation are summarized in Research Note PG-12-3 (Coopersmith *et al.* 1998) in this series.

THE BOBTAIL ROAD STUDY AREA

The Bobtail Road trial of EP 660 is contained within the Cluculz Lake Silviculture Demonstration Area, an area of varied silviculture trials in use since 1964. The trial is located at km 20 of the Bobtail Forest Service Road and is located in the Vanderhoof Forest District (Figure 1). The study plots straddle district lots 4970 and 4971 (123° 30'W, 53° 51'N). Mean elevation of the study area is approximately 840 m. The study area is classified within the sub-mesic to mesic white spruce - Douglas-fir - Rice grass site series of the Stuart dry warm Sub-Boreal Spruce biogeoclimatic sub-zone (SBSdw3/04, DeLong *et al.* 1993). Prickly rose (*Rosa gymnocarpa* Nutt.) and Sitka mountain alder (*Alnus viridis* [Chaix] DC. spp. *sinuata* [Regel] Love and Love) are the dominant shrubby vegetation on site. Soils underlying the study area consist of Brunisolic Gray Luvisols and Orthic Gray Luvisols belonging to the Deserters Soil Association (Dawson 1989). The Deserters soil association is one of the most common soil associations occurring on land forms between Prince George



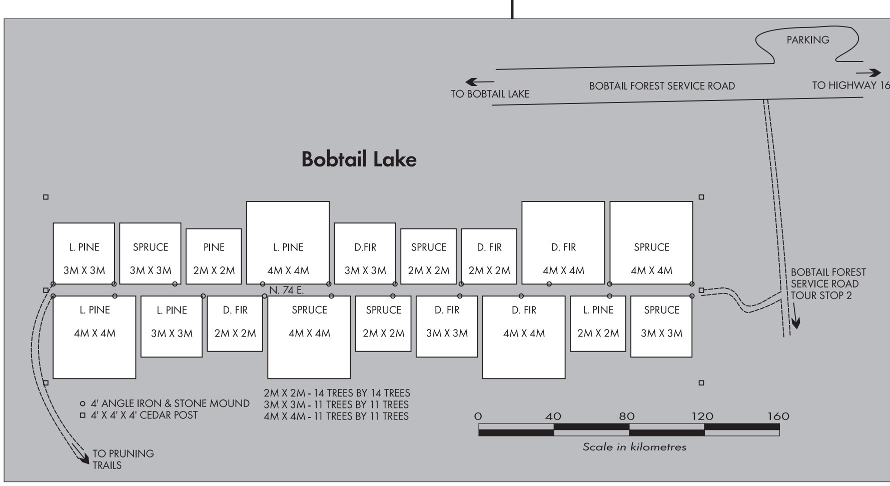


FIGURE 1. Location and plot layout of the Bobtail Road EP 660 Installation.

and Vanderhoof. It occurs on land forms composed of basal till that have been deposited and moulded by glacial ice. Drumlins of various sizes account for the hilly nature of the study location. The glacial till is medium to moderately fine textured gravely loams to gravely clay loams, although this is highly variable within the study plots. In places the soils are very gravely and stones are common throughout. The rooting depth of the soils is shallow, generally ‹50 cm. The plots slope gradually (‹5 %) to the northwest.

The area was clearcut logged in the early winter of 1964-65 and broadcast burned in the late fall of 1965. This was one of the first operational applications of prescribed burning following logging in the Vanderhoof District. Most of the area was left for natural regeneration, presumably for lodgepole pine. An interesting mix of pine and trembling aspen now occupies much of the area surrounding the trial. The study plots were laid out and planted in 1967.

STUDY DESIGN AND MEASUREMENT SCHEDULE

The EP 660 trial uses a factorial design. Three planting espacements (factor 1: 2 m x 2 m or 2197 sph, 3 m x 3 m or 1076 sph, and 4 m x 4 m or 637 sph) were used for each of the three species (factor 2: lodgepole pine, white spruce and Douglas-fir). This 3 x 3 design results in 9 treatment combinations per replicate. Two replicates of 9 plots were used at each installation, resulting in 18 plots per installation (Figure 1). Treatments were assigned to plots randomly within replicates.

Treatments were planted as either 11 rows by 11 rows or 14 rows by 14 rows depending upon available space. However, assessments were confined to the central 7 rows by 7 rows of trees, or 49 trees per species x spacing x replicate combination. This meant that the measurement plots were surrounded by a minimum of two and a maximum of four buffer rows per plot. The plantation was measured in 1977 (year 10), 1981 (year 15), 1986 (year 20), 1991 (year 25) and 1996 (year 30). However, growth measurements were adjusted by 2 years (for lodgepole pine and Douglas-fir) or by 3 years (for white spruce) to account for time since germination in the nursery. Analysis of height and diameter growth for the trial was performed using a repeated measures analysis of variance (ANOVA) procedure. Basal areas (outside bark) were calculated from measured diameters using standard formula (Wenger 1984). Total tree volumes were calculated using the equations for juvenile trees from Kovats (1977).

Complete brushing and weeding of the plots and boundaries took place in 1979, 1983, 1986 and 1996/97. During the first measurement in 1977 the trees were not numbered. In 1981, the study trees were tagged, but many of these original tags were lost. All trees in the plots were re-tagged in 1986. However, the pattern of live and dead trees within the plots dating back to 1981 has allowed us to positively match trees between measurement years regardless of lost tag number.

In the fall of 1997, the Douglas-fir at the Bobtail Road installation were pruned to a height of 3 m, or to 50% of their live crown height where total height was ‹6 m. Both pruning saws and pruning shears were used, although the shears proved ineffective for the very large branch diameters in most of the stand and were soon discarded. The pruning saws, although slower than the shears, could reach much easier to the desired 3 m height and produced a much cleaner cut and smaller branch nub. Pruning was done to allow tag numbers to be attached at breast height to tree boles with 3 inch zinc-coated box nails, and to facilitate easier site visits and measurements which were becoming difficult because of the thick tangle of branches in most plots. Prior to the pruning, the tags on the Douglas-fir were strung from the lower branches with wire. Most of these lower branches were dead, and some tags have been lost as these branches broke. The lodgepole pine on site were pruned in 1986. A similar pruning operation is planned for the white spruce plots in 1998.

RESULTS

Table 1 and Figures 2 through 5 summarise the changes in height and diameters and calculated volumes and basal areas that have been observed at Bobtail Road since 1967. Table 2 summarises the findings of the repeated measures ANOVA for changes in height and diameter with species and spacing at Bobtail Road.

EFFECTS OF SPECIES AND SPACING ON TOP HEIGHT AND QUADRATIC MEAN DIAMETERS

The stands at Bobtail Road appear to be well stratified by species in terms of both top height (P›.000, Table 2) and quadratic mean diameter (P‹000, Table 2) (Top height is defined as the average height of the 10 tallest trees per hectare; quadratic mean diameter is the diameter of the tree of average basal area, Daniel *et al.* 1979). Not surprisingly, lodgepole pine contains on average both the tallest and the largest diameter trees in the plantation, followed by Douglas-fir and white spruce. The tallest individual lodgepole pine are now‹ 24 m tall with top heights 13 - 14 m depending upon espacement (Figure 2a). By comparison, the tallest Douglas-fir at Bobtail Road are now 26 m tall; however, mean top heights for Douglas-fir are 10 - 12 m (Figure 2c). The Douglas-fir at the Bobtail installation suffered significant amounts of top dieback (probably as a result of frost) some 8 to 10 years ago. Where individual trees managed to escape this abiotic event, top heights are now equal to or exceed those of lodgepole pine. However, in general the damage to the Douglas-fir stands was widespread enough to significantly lower the mean plot heights and top heights of all Douglas-fir on site. The tallest white spruce were measured at just under 20 m height with average top heights of 9 - 10 m (Figure 2b).

In comparison to top heights, there were smaller differences between species for quadratic mean diameters. Lodgepole pine again had the largest quadratic mean diameters, varying between approximately 13.5 cm and 17.1 cm depending upon espacement (Figure 3a). Douglas-fir was not much smaller, with quadratic mean diameters 12.3 - 16.4 cm (Figure 3c). White spruce was again much smaller than either lodgepole pine or Douglas-fir, with quadratic mean diameters 8.5 - 13.0 cm (Figure 3b).

In contrast to the more obvious species effect observed at the Bobtail Road installation, initial spacing did not have as dramatic an effect on average height ($p<.039$, Table 2). Although still statistically significant, of the three species only Douglas-fir seemed to exhibit a strong espacement effect on height growth, with the tallest trees being found in the highest density 2 m x 2 m espacement. After 30 years, there is virtually no difference in the top heights between espacements for either lodgepole pine or white spruce. This reinforces the common silvicultural observation that height growth (and thus site index) is set more by climate and soil than it is by plantation density, except at the extremes (both high and low) of stand density (Daniel *et al.* 1979).

Spacing did have a very strong influence on quadratic mean diameters, however ($P<000$, Table 2). For all three species, quadratic mean diameters were inversely related to density. The largest quadratic mean diameters were found in the lowest density 4 m x 4 m espacement plots, followed respectively by the 3 m x 3 m and the 2 m x 2 m plot quadratic means. This relationship has been shown for all commercial forest species in North America (Daniel *et al.* 1979).

BASAL AREA AND VOLUME CHANGES OVER TIME

Since basal area is directly related to diameter, it is not surprising that the basal area development of lodgepole pine and Douglas-fir are very similar at Bobtail Road (Figure 3). It is similarly not surprising that the highest density plots have the greatest calculated basal areas. In the highest density 2 m x 2 m plots, Douglas-fir basal area (27.22 m^2/ha) now surpasses lodgepole pine basal area (26.17 m^2/ha). We continue to observe additional mortality, principally in the lodgepole pine plots. A number of the lodgepole pine have stem infections of Western Gall Rust (*Endocronartium harknessii* [J.P. Moore] Y. Hirat). Although branch galls are the more commonly observed infection vector for this disease, they are rarely fatal. However, where the galls form on the stem, mortality does occur, often decades after the initial infection (Finck *et al.* 1987). The infected tree can be killed either directly by the complete girdling of the stem by the gall, or by wind-breakage at the canker-weakened point (the more common phenomenon observed in the Bobtail Road plots). Since the 1991 evaluation where 83 live trees were measured in the 2 m x 2 m lodgepole pine plots, there have been 3 additional dead trees recorded. All three of these trees were broken by wind at stem cankers. Since trees infected with stem cankers can reach substantial diameters before they die, the loss of these trees does significantly affect the calculation of both basal area and volume. By comparison, there has been no recorded mortality in the closest espacement Douglas-fir plots since 1981.

The rate at which new basal area is being added to the lodgepole pine plots appears to have peaked, perhaps as early as the 15 year evaluation in 1981 for the 2 m x 2 m plots (Figure 4a). For both white spruce and Douglas-fir however, there is no sign yet that their rates of basal area increment have slowed (Figures 4b and 4c).

Lodgepole pine plots contain substantially greater total volumes compared with both Douglas-fir and white spruce. Average total volumes in the 2 m x 2 m lodgepole pine are now approaching 95 m^3/ha compared with approximately 48 m^3/ha for Douglas-fir and only 20 m^3/ha for white spruce (Figure 5, Table 1). Mean annual increments for the highest density lodgepole pine plot are now more than 3 m^3/ha/yr, nearly twice that of Douglas-fir (1.6 m^3/ha/yr) and nearly five times that of white spruce (0.6 m^3/ha/yr). Since volume calculations utilise both height and diameter components, the greater height of lodgepole pine would on average account for the greater observed amounts of volume for this species.

Only the highest density (2 m x 2 m) lodgepole pine plots have 5-year periodic annual increments (PAI's) for the 1991-96 period that are less than their 1986-91 values. The PAI for these lodgepole pine plots went from 6.17 m^3/ha/yr in 1986-91 to 4.09 m^3/ha/yr in the period 1991-96. PAI's are known to peak before MAI's do. Peaking of PAI's is often cited by silviculturist as the point at which the stand is entering the "stem exclusion" phase of stand development. This is the period within which mortality due to inter-tree competition can be expected (Oliver and Larson 1990). The 1991-96 calculated PAI's for all other species and espacements combinations at Bobtail are still increasing relative to the 1986-91 increments.

COMPARISON OF STAND DENSITY INDICES AT BOBTAIL

It is often difficult to compare the growth rates of stands of different species grown at different densities. This problem is often tackled by using various relative density measures or stand density indices which are independent of site and age (Larson and Cameron 1986). Two of the most useful indices are Reineke's Stand-Density Index (SDI) (Reineke 1933, [in Daniel *et al.* 1979]) and Curtis' relative density (RD) (Curtis 1982).

SDI is the oldest of the indices and is probably the most commonly used in growth and yield literature. Reineke observed that all single-species, even-aged, fully stocked stands of the same quadratic mean diameter will have approximately the same number of stems/ha regardless of site quality or stand age (Daniel *et al.* 1979). Stands will differ in the amount of time necessary to reach a given quadratic mean diameter. Better quality sites will produce trees of larger diameter faster than will poorer sites. However, when they reach the same quadratic mean diameter, they will all have the same approximate density. The relationship of the natural log of density to the natural log of quadratic mean diameter has a near constant slope of -1.605 for many forest species (Larson and Cameron 1986) and can be used to compare stands at various stages of development. SDI for a given stand is the number of trees at equivalent relative density when the average dbh is 25 cm. For coastal Douglas-fir, the maximum observed SDI is 1510 trees/ha while several species of pine ranged in SDI values from a low of 1015 trees/ha (longleaf pine [*Pinus palustris* Mill.]) to a high of 2106 trees/ha (Ponderosa Pine [Pinus *ponderosa* Doug. ex Lawson & Lawson]) (Larson and Cameron 1986).

SDI has increased steadily in all plots at Bobtail Road since the first measurements in 1977 (Table 1). The maximum SDI observed at the Bobtail Road site was 722 sph for the 2 m x 2 m lodgepole pine plots. Only the SDI for the 2 m x 2 m Douglas-fir plots (677 sph) are close to the values for the lodgepole pine plots. All other SDI values are approximately half of these values or less. The SDI's observed at Bobtail are still well below the listed maximum found in the literature for Ponderosa pine, the pine species most similar to lodgepole pine. This should mean that the stands at Bobtail will continue to grow with little additional mortality due to intra-species competition. Tree mortality will continue at Bobtail Road, however, especially in the lodgepole pine plots as a result of gall rust infections.

Curtis' relative density (RD) measurement is similar to SDI except that it uses basal area and quadratic mean diameter in its calculation. Values of RD range from 0 to 14 for coastal Douglas-fir. Like SDI, values of RD tend to increase over time, but can fluctuate widely as trees self thin. Because very small trees can remain alive for long periods of time, they can drastically affect RD calculations. Events such as a heavy wind storms or dry summers, which tend to remove the smallest and most moribund individuals within stands first, can cause very marked jumps in SDI (Larson and Cameron 1986).

At Bobtail, the Douglas-fir 2 m x 2 m plots had the highest

TABLE 1: Summary of the 30 year measurements for all 3 species at the Bobtail Road Installation of EP 660.

A: LODGEPOLE PINE

Year	1977			1981			1986			1991			1996		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	17	17	17	21	21	21	26	26	26	31	31	31
sample n	96	95	96	90	85	92	87	88	92	83	79	91	80	80	90
stems/ha	2153	1044	624	2018	934	598	1951	967	598	1861	868	592	1794	879	585
average ht. (m) (se)	3.43 (0.11)	3.45 (0.12)	2.98 (0.11)	6.27 (0.20)	6.00 (0.20)	5.31 (0.19)	8.29 (0.24)	8.00 (0.24)	7.24 (0.23)	10.86 (0.42)	10.87 (0.43)	9.56 (0.40)	11.68 (0.41)	11.95 (0.38)	11.27 (0.38)
top height[2] (m) (sd)	4.68 (0.24)	4.55 (0.17)	4.03 (0.37)	8.07 (0.51)	7.29 (0.46)	6.69 (0.37)	9.96 (0.03)	9.38 (0.33)	8.76 (0.23)	13.33 (0.25)	12.58 (0.37)	11.49 (0.33)	13.63 (0.69)	13.62 (0.25)	13.35 (0.39)
sample n[1]			95		70										
arithmetic mean diameter (cm) (se)	1.47 (0.12)	1.57 (0.12)	1.37 (0.12)	8.23 (0.28)	8.91 (0.34)	8.47 (0.28)	10.49 (0.40)	12.11 (0.40)	11.59 (0.39)	12.16 (0.41)	14.48 (0.42)	14.75 (0.39)	13.48 (0.38)	16.05 (0.38)	17.06 (0.35)
quadratic mean diameter (qmd) (cm)	1.51	1.67	1.43	8.39	9.06	8.68	10.65	12.25	11.88	12.32	14.65	15.03	13.63	16.29	17.36
basal area (m^2/ha)	0.38	0.23	.10	11.17	4.97	3.54	17.38	11.41	6.63	22.18	14.63	10.49	26.17	18.33	13.85
Relative Density (RD) (ba/qm$^{d.5}$)	0.31	0.18	0.08	3.86	1.65	1.20	5.33	3.26	1.92	6.32	3.82	2.71	7.09	4.54	3.32
Reineke's SDI	23.80	13.57	6.32	349.84	183.17	109.5	495.97	307.75	181.2	597.7	368.13	261.61	677.63	442.01	325.79
Total Volume (m^3/ha)	0.45	0.27	0.1	20.99	8.74	5.52	43.39	26.67	14.24	74.24	45.77	30.06	94.69	65.86	46.92
mean annual increment (MAI) (m^3/ha/yr)	0.038	0.023	0.008	1.235	0.514	0.325	2.066	1.270	0.678	2.855	1.760	1.156	3.055	2.125	1.514
5-year periodic annual increment (PAI) (m^3/ha/yr)				4.108	1.694	1.084	4.480	3.586	1.744	6.170	3.820	3.164	4.090	4.018	3.372

[1]Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2]Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. While for the 4 m x 4 m plots, this average is based on the tallest 15 trees.

RD at 7.62, followed closely by 2 m x 2 m lodgepole pine at 7.09 (Table 1). The highest RD for white spruce was 4.13 for the 2 m x 2 m plots. The values for the 3 m x 3 m and 4 m x 4 m plots were all approximately one half or less of the values for the 2 m x 2 m plots for each species, respectively. As for SDI, the observed RD values are still well below the values where we would expect to see self-thinning losses due to intra-species competition. Larson and Cameron (1986) ran a simulated thinning experiment through the Tree and Stand Simulator model (TASS, Mitchell 1975). Starting with a plot of Douglas-fir planted to 1110 sph (3 m square spacing) they thinned (by low thinning) to 361 sph at age 32 and 158 sph at age 47. At the time of the first thinning RD was 7.2. The first thinning reduced RD to 3.3. It subsequently recovered to 5.5 at the time of the second thinning and was again reduced, this time to 2.7 by the second operation.

FUTURE LUMBER VALUES

One of the advantages of utilising higher plantation densities is that the live crowns of closely-planted stands lift faster than the live crowns in widely-spaced stands. The lower boles of densely planted stands have smaller branches and subsequent smaller knots when these branches die. The smaller live crown of very dense stands produce lower percentages of juvenile wood which normally translates to higher wood quality (Cannell 1985).

The crowns of Douglas-fir at Bobtail are the densest of the 3 species in this trial. In the 2 m x 2 m plots (2196 sph initial density) and the 3 m x 3 m plots (1076 sph initial density), the live crowns on most of the trees start at 3 - 5 m above the root collar. These stands are very dark, with little in the way of undergrowth beneath them. The widest espacement Douglas-fir generally have live branches at or near the root collar, and the lowest live branches on these trees are exceeding large (generally ›5 cm).

TABLE 1: Continued. **B: WHITE SPRUCE**

Year	1977			1981			1986			1991			1996		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	13	13	13	18	18	18	22	22	22	27	27	27	32	32	32
sample n	98	96	98	96	93	95	96	96	95	96	92	95	96	91	95
stems/ha	2196	1055	637	2153	1022	618	2153	1055	618	2153	1011	618	2153	1000	618
average ht. (m)	1.25	1.19	1.33	2.12	2.31	2.59	3.07	3.57	4.00	4.24	5.15	5.57	5.78	6.85	7.52
(se)	(0.11)	(0.11)	(0.11)	(0.19)	(0.19)	(0.19)	(0.23)	(0.23)	(0.23)	(0.39)	(0.40)	(0.39)	(0.37)	(0.38)	(0.37)
top height[2] (m)	2.38	2.03	1.85	4.03	3.85	3.65	5.61	5.60	5.44	7.68	7.62	7.62	9.05	9.54	9.73
(sd)	(0.38)	(0.27)	(0.23)	(0.23)	(0.21)	(0.54)	(0.43)	(0.35)	(0.61)	(0.48)	(0.38)	(0.38)	(0.38)	(0.48)	(0.74)
sample n[1]				84	84	93	92	92		95			95		
arithmetic mean diameter (cm)				2.20	2.50	2.86	3.88	4.59	5.53	5.81	7.49	9.05	8.05	10.52	12.63
(se)				(0.29)	(0.29)	(0.28)	(0.39)	(0.39)	(0.38)	(0.38)	(0.39)	(0.38)	(0.35)	(0.35)	(0.35)
quadratic mean diameter (qmd) (cm)				2.53	2.83	3.11	4.24	4.98	5.85	6.25	7.92	9.40	8.48	10.92	12.99
basal area (m^2/ha)				0.94	0.57	0.46	2.91	1.97	1.66	6.52	4.98	4.29	12.04	9.47	8.18
Relative Density (RD) (ba/qm$^{d.5}$)				0.59	0.34	0.26	1.41	0.88	0.69	2.61	1.77	1.40	4.13	2.87	2.27
Reineke's SDI				54.50	30.97	21.79	124.82	79.18	60.06	232.67	159.78	128.58	379.69	264.64	216.09
Total Volume (m^3/ha)				0.67	0.42	0.34	2.74	2.03	1.79	8.03	7.04	6.22	19.57	16.71	15.65
mean annual increment (MAI) (m^3/ha/yr)				0.037	0.023	0.019	0.125	0.092	0.081	0.297	0.261	0.230	0.612	0.522	0.489
5-year periodic annual increment (PAI) (m^3/ha/yr)				0.134	0.084	0.068	0.414	0.322	0.290	1.058	1.002	0.886	2.308	1.934	1.886

[1] Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2] Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. While for the 4 m x 4 m plots, this average is based on the tallest 15 trees.

The crowns of lodgepole pine have also lifted dramatically in the 2 m x 2 m plots. In these plots, live crowns are now confined to crown positions between 5 m and 9 m above root collar. However, as density decreases, the live crown for this species increases dramatically. In both the 3 m x 3 m and the 4 m x 4 m plots, there are live lower branches that start at the first branch (approximately 2 m after the 1986 pruning). Many of these branches now extend >3.5 m from the bole of the tree. Many branch diameters are now as large as 8 cm.

The crowns in the white spruce stands have not lifted appreciably in the first 30 years of the trial. Most trees have live crowns that extend to the ground. However, unlike Douglas-fir and lodgepole pine, most of the lowest live branches in spruce are quite small, the crowns are very columnar, and the branch diameters are not exceedingly large.

Despite the crown lift observed for both Douglas-fir and lodgepole pine at higher densities, there has been little natural pruning of branches in these stands. Dead branches of both species had to be manually pruned in order to produce clear boles.

CONCLUSIONS

- Currently there are clear differences between the 3 species in terms of top height over the first 30 years of the EP 660 trials at Bobtail Road. Lodgepole pine is the tallest species on site, followed by Douglas-fir and white spruce, respectively. Much of this difference in top height between Douglas-fir and lodgepole pine can be attributed to abiotic events (probably frost) which have damaged the Douglas-fir on site more heavily than either of the other two species.
- There are much smaller species differences for quadratic mean diameters than for height. In fact, Douglas-fir is now the largest tree on site in terms of QMD, followed closely by lodgepole pine. White spruce continues to lag behind the other two species in both height and diameter growth.

TABLE 1: Continued. **C: DOUGLAS-FIR**

Year	1977			1981			1986			1991			1996		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	17	17	17	21	21	21	26	26	26	31	31	31
sample n	98	91	97	95	87	96	95	87	95	95	86	95	95	86	95
stems/ha	2197	1000	631	2130	956	624	2130	956	618	2130	945	618	2130	945	618
average ht. (m) (se)	1.96 (0.11)	1.61 (0.12)	1.85 (0.11)	3.86 (0.19)	3.13 (0.20)	3.63 (0.20)	5.59 (0.23)	4.55 (0.24)	5.32 (0.23)	7.29 (0.39)	6.12 (0.41)	7.25 (0.39)	8.35 (0.37)	7.25 (0.39)	8.71 (0.37)
top height[2] (m) (sd)	3.53 (0.35)	2.63 (0.17)	2.87 (0.29)	6.34 (0.40)	4.92 (0.24)	5.50 (0.34)	8.63 (0.46)	9.11 (0.83)	7.57 (0.43)	10.90 (0.50)	9.26 (0.48)	9.95 (0.39)	11.88 (0.50)	10.37 (0.70)	11.42 (0.57)
sample n[1]					83	94									
arithmetic mean diameter (cm) (se)				4.58 (0.28)	3.94 (0.30)	4.75 (0.28)	7.51 (0.38)	6.49 (0.40)	8.00 (0.38)	10.42 (0.38)	10.54 (0.41)	12.61 (0.38)	12.25 (0.35)	12.97 (0.38)	16.42 (0.35)
quadratic mean diameter (qmd) (cm)				5.03	4.31	5.21	7.96	7.02	8.69	10.83	11.04	13.29	12.75	13.53	17.16
basal area (m^2/ha)				4.22	1.33	1.30	10.61	3.62	3.67	19.62	8.93	8.57	27.22	13.58	14.28
Relative Density (RD)(ba/$qmd^{.5}$)				1.88	0.64	0.57	3.76	1.37	1.25	5.96	2.69	2.35	7.62	3.69	3.45
Reineke's SDI				162.44	56.90	50.35	339.35	124.49	113.30	556.24	254.51	224.16	722.82	352.75	337.83
Total Volume (m^3/ha)				3.79	0.96	1.09	12.98	3.48	4.16	30.65	11.19	12.55	48.07	19.52	23.93
mean annual increment (MAI) (m^3/ha/yr)				0.223	0.057	0.064	0.618	0.166	0.198	1.179	0.430	0.483	1.551	0.630	0.772
5-year periodic annual increment (PAI) (m^3/ha/yr)				0.758	0.192	0.218	1.838	0.504	0.614	3.534	1.542	1.678	3.484	1.666	2.276

[1] Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2] Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. While for the 4 m x 4 m plots, this average is based on the tallest 15 trees.

- Abiotic damage (probably frost) has affected virtually every Douglas-fir at Bobtail Road. This has resulted in substantial height growth losses in these stands. We are not sure if the seedlot of Douglas-fir used in the EP 660 trial was particularly frost-prone, or if the Bobtail Road site is an exceptionally frost-prone area for this site series. However, it does raise a red flag for any forester contemplating using Douglas-fir in this area. If frost-hardy stock is available, however, the growth rate of Douglas-fir that we have observed at Bobtail Road, its' resistance to common pests and pathogens relative to other species like lodgepole pine, and the potential value of lumber derived from this species make it a very attractive alternative to either lodgepole pine or white spruce on the right site.
- We continue to loose approximately 0.5 % of lodgepole pine every year to wind snap at gall infection points on stems. Overall survival of lodgepole pine at Bobtail is now approximately 85%. However, most of the lodgepole pine at Bobtail Road have branch galls on them, and a substantial number also have stem galls. The losses in these stands will continue well into the foreseeable future. Forest managers must account for the long-term susceptibility of this species to mortality agents such as gall rust by developing and using disease-resistant stock types, keeping plantation densities high or encouraging additional natural regeneration of pine at the time of plantation establishment. Considering all of the pests and pathogens that can affect this species (often occurring decades after initial plantation establishment), target stocking levels and acceptable minimum stocking levels in regional stocking standards should be raised substantially for lodgepole pine.
- Although the live crowns of both lodgepole pine and Douglas-fir are now lifting in the two highest density treatments, the lowest branches (whether live or dead) in these stands now have very large diameters. These large lower branches will result in very large knots, significantly lowering the future wood quality that can be achieved from these stands. The crowns of all three species in the lowest density plots extend almost to the ground. Since these plots are very close to target minimum stocking levels from the Prince George regional stocking standards (generally 700 - 1200 stems/ha, Anonymous 1993), we should not expect the crowns to lift quickly in any stands within the region that are grown at or close to minimum stocking levels. Stand densities should be high enough to cause the crowns of Douglas-fir and lodgepole pine to lift quickly, limiting the size of knots If future wood quality is perceived to be an important issue within the Prince George Region, then higher target and minimum stocking densities must become standard.
- The stand densities tested at the Bobtail Road installation were not high enough to induce natural pruning in any of the three species tested. Given the target and minimum stocking standards of current planting in the Prince George Region, manual pruning will be necessary in most plantations if clear wood is the objective.

TABLE 2: Summary of the repeated measures analysis of variance (ANOVA) for height and diameter growth differences for the 3 species and 3 spacings at Bobtail Road. The repeated measures ANOVA was given REPxSPECIESxSPACING means as input terms rather than individual tree data in order to get the correct error term in the model. The reported F values and probability tests are for the Wilkes-Lambda test which is the correct F test for repeated measures analysis. Because only lodgepole pine has DBH recorded for the 1977 measurement, the repeated measures analysis was done on the 1981-1996 data. This results in reduced degrees of freedom (df) for this portion of the analysis. Analysis for height was done with 1977 to 1996 data.

Source	Sum of Squares	df	Mean Square	F value	Probability[1]
DBH					
Year	676.519	3	225.506	9292.619	0.000
Year*Species	15.291	6	2.549	48.607	0.000
Year*Spacing	25.397	6	4.233	31.30	0.000
Year*Species*Spacing	1.127	12	0.094	3.480	0.008
Error	0.971	27	0.036		
Height					
Year	516.113	4	129.028	1520.754	0.000
Year*Species	22.248	8	2.781	18.290	0.000
Year*Spacing	1.330	8	0.166	3.068	0.039
Year*Species*Spacing	2.401	16	0.150	1.821	0.106
Error	2.336	36	0.065		

[1]Probabilities less than 0.05 are considered significant

TABLE 3: Summary of the regression lines of best fit for height data at the Bobtail Road installation. The equations are all quadratic in form, indicating that height growth is no longer linear with age. The equations do not include a constant. In most instances, the fit was better without a constant (higher r^2 values). The equations also make more biological sense when they are fit through the origin rather that an intercept.

Effect	Level	Equation	r^2
species	lodgepole pine	$ht = 0.27\,(age) + 3.959\times10^{-3}\,(age^2)$	0.99
	white spruce	$ht = 0.02\,(age) + 0.01\,(age^2)$	0.98
	Douglas-fir	$ht = 0.12\,(age) + 4.784\times10^{-3}\,(age^2)$	0.99
spacing	2 m x 2 m	$ht = 0.19\,(age) + 2.865\times10^{-3}\,(age^2)$	0.88
	3 m x 3 m	$ht = 0.15\,(age) + 4.293\times10^{-3}\,(age^2)$	0.89
	4 m x 4 m	$ht = 0.13\,(age) + 0.01\,(age^2)$	0.94

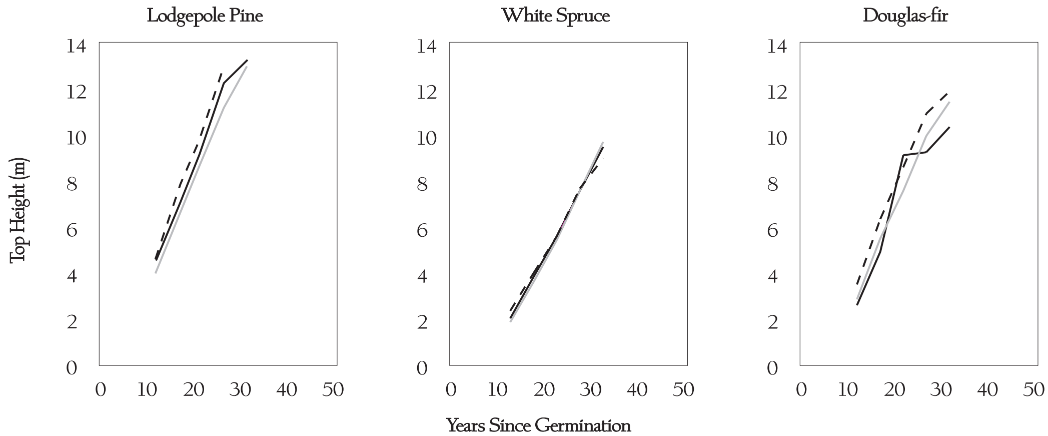


FIGURE 2. Changes in top height over time at the Bobtail Road Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

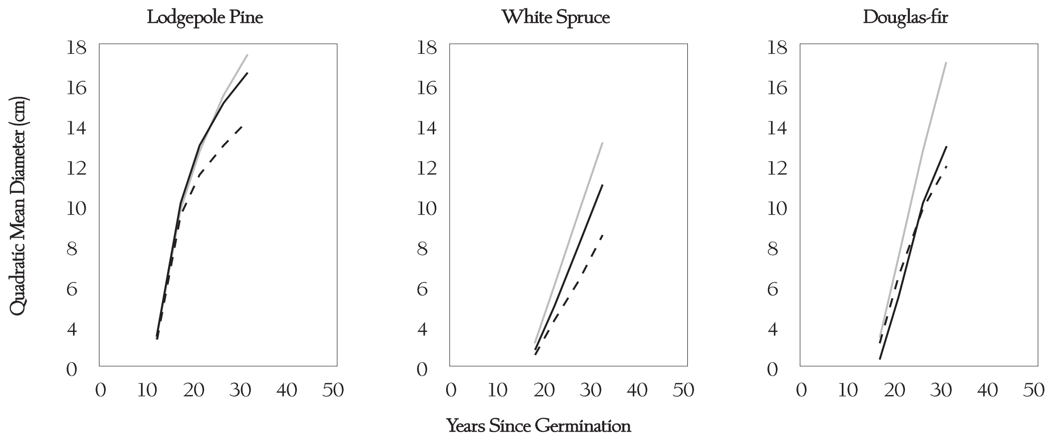


FIGURE 3. Changes in quadratic mean diameter over time at the Bobtail Road Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

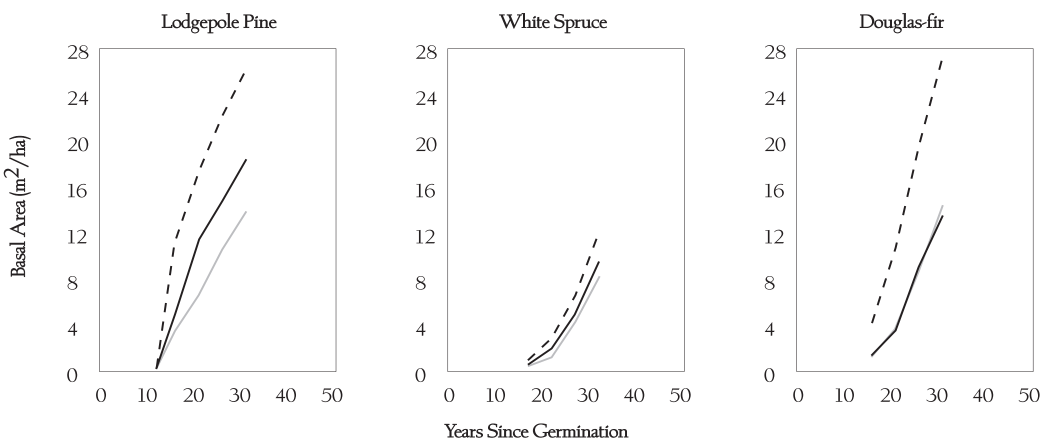


FIGURE 4. Changes in summed basal area over time at the Bobtail Road Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

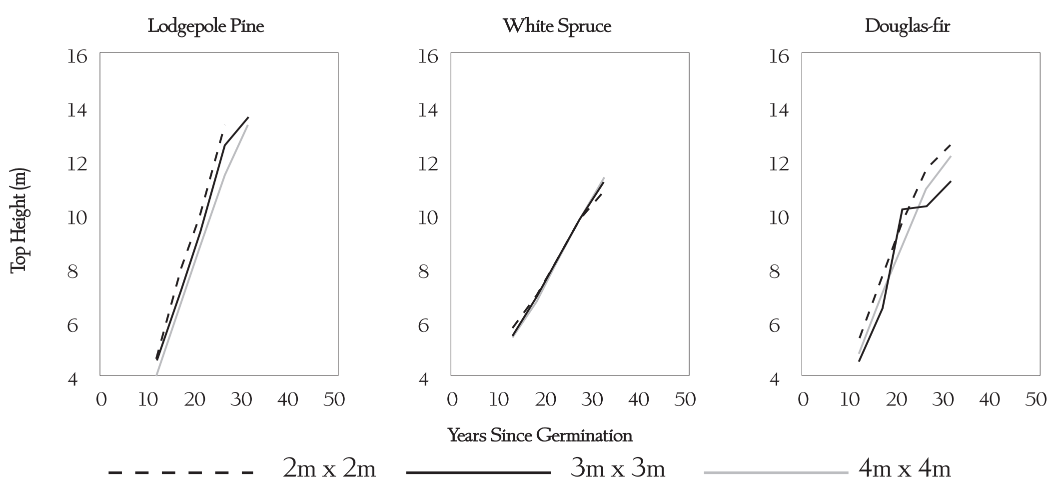


FIGURE 5. Changes in summed total volume over time at the Bobtail Road Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

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EXPERIMENTAL PROJECT 660 - A 30-YEAR PROGRESS REPORT: CHILCO CREEK INSTALLATION

DAVE COOPERSMITH, BRUCE ROGERS AND VERA SIT

INTRODUCTION

The choice of which tree species to plant following harvest and the density of planting are fundamental choices by foresters at the beginning of a rotation. These choices will influence not only the future options available to foresters, but also many of the final outcomes at subsequent harvest. They are also the two factors most easily controlled by the forester (Daniel *et al.* 1979).

Plantation density is known to have the greatest initial effect on mean tree size (quadratic mean diameter, also known as average stand diameter) and subsequently, if densities are high enough, on final yield at rotation (Daniel *et al.* 1979). However, density also strongly affects the height of the live crown. Stands grown at high density have live crowns concentrated in their upper boles. This results in trees with less taper and greater proportions of mature wood to juvenile wood when compared to trees grown at lower densities. It is rare in the Prince George Region for target stocking densities to go above 1200 stems per hectare (sph) (Anonymous 1993). Stands that are grown at such densities usually have very large live crowns, maintain live branches for long periods of time on the lower bole and have very large branch diameters. These characteristics can result in lower wood quality at final harvest.

Relative to other areas of British Columbia (BC) with more southern or coastal climates, foresters working in boreal and sub-boreal forests of north-central BC have relatively few species of conifers to choose from. More than 97.4% of all the planting within the Prince George Region is accomplished with only two species; interior white spruce (*Picea glauca* [Moench] Voss) and lodgepole pine (*Pinus contorta* Doug. *ex.* Loud.) (Anonymous 1997). Together, these two species represent only 74.2% of the volume of billed stumpage within the Region. Other species such as Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), sub-alpine fir (*Abies lasiocarpa* [Hook.] Nutt.), western redcedar (*Thuja plicata* Donn *ex* D. Don in Lamb.) and western hemlock (*Tsuga heterophylla* [Raf.] Sarg.) are under-represented in the numbers of seedlings replanted versus their billed volumes. We can interpret these data as indicative of a bias towards species which are known to have very fast initial growth following out-planting. Tree species that lack fast initial growth, those that have real or perceived problems at establishment with frost and other abiotic site factors, or those species which are utilised so seldom that little operational experience in growing or planting them exists have traditionally been avoided in the Prince George Region.

The bias towards fast initial height growth is understandable. In BC silviculture prescriptions must specify time lines for stands to reach a "free growing" condition following harvesting. A free growing stand is defined as "a stand of healthy trees of a commercially valuable species, the growth of which is not impeded by competition from plants, shrubs or other trees" (Anonymous 1995). Species with slower initial height growth will take longer to reach the minimum heights necessary to be declared

PHOTO 1: 3 m x 3 m lodgepole pine.
PHOTO 2: 3 m x 3 m white spruce.

The growth of both spruce and pine at Chilco Cr. was some of the best observed of the three EP660 installations.

free growing, or may require additional silvicultural treatments to reach free growing.

This bias may have unforeseen consequences. While tree species such as lodgepole pine do display very good initial growth, these species differences in growth rate often decrease dramatically the older the stands get (Bella and De Franceschi 1974). Species which display very fast initial growth also tend to be highly susceptible to pest and pathogen problems (e.g. red squirrel [Sullivan *et al. 1996]* and western gall rust [Van der Kamp 1981] damage to young lodgepole pine stands). Very often these agents damage trees well past the age that free growing is declared. Other species may indeed have slower initial growth, but offer much greater resistance to pests and pathogens. Over the course of a rotation it may be that resistance to a wide range of pests, pathogens and abiotic damage is much more important for the achievement of management objects than is initial growth rate

Experimental Project (EP) 660 is a long-term plantation study examining the influence of planting density (espacement) on the growth performance of white spruce, Douglas-fir and lodgepole pine. Established in 1967, this study is one of the oldest plantation studies in northern BC.

The Chilco Creek study area is one of three EP 660 installations surrounding Prince George. These three study installations were created at the same time using the same experimental methodology and planting stocks. Details on the EP 660 study rationale and methodology are reported in Research Note PG-12 (Coopersmith *et al.* 1997a). Results from the Buckhorn Ridge trial are summarized in Research Note PG-12-1 (Coopersmith *et al.* 1997b), while those for the Bobtail Road installation are summarized in Research Note PG-12-2 (Coopersmith *et al.* 1998) in this series.

THE CHILCO CREEK STUDY AREA

The Chilco Creek study area is located approximately 65 km northwest of Prince George and 30 km northeast of Vanderhoof along the Sackener Road (figure 1). The study plots are located within district lot 5384 (123° 43' W, 54° 41' N, NTS grid map 093J-002). Mean elevation of the study area is approximately 760 m. Like the Bobtail Road study area, the Chilco Creek installation is located in the Stuart dry warm Sub-Boreal Spruce biogeoclimatic sub-zone. However, the Vanderhoof installation is moister than the Bobtail installation, and is located in the mesic to sub-hygric spruce - Pink spirea - Prickly rose site series (SBSdw3/06, DeLong *et al.* 1993). Prickly rose (*Rosa gymnocarpa* Nutt.) Sitka mountain alder (*Alnus viridis* [Chaix] DC. spp. *sinuata* [Regel] Love and Love) and various willow species (*Salix* spp.) are the dominant shrubby vegetation on site.

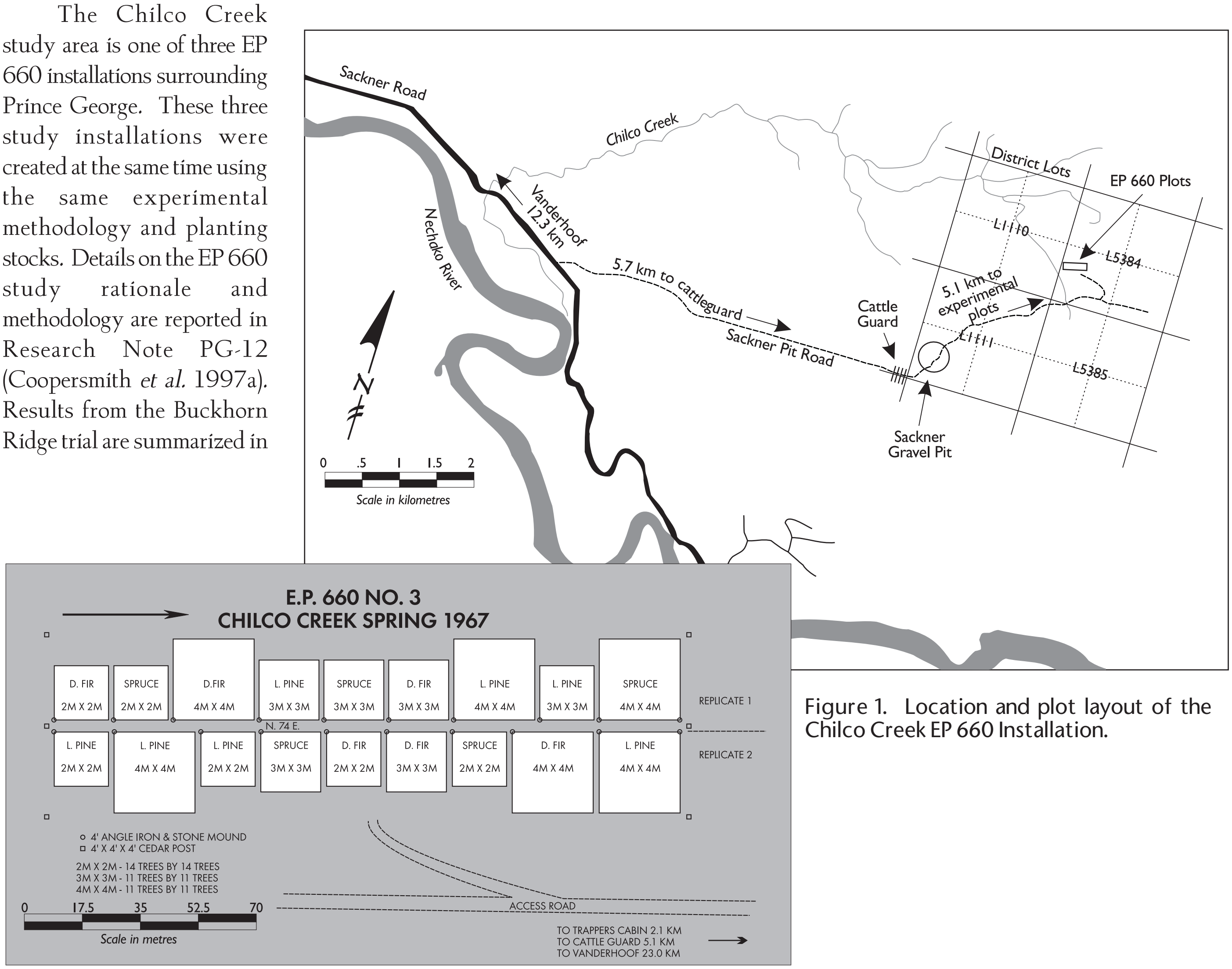

Figure 1. Location and plot layout of the Chilco Creek EP 660 Installation.

Soils underlying the study area consist of complexes of fine-textured Orthic Grey Luvisols belonging to the Vanderhoof-Pineview-Barrett map complex (Dawson 1989). The fine-textured Vanderhoof and Pineview Soil Associations of this complex are formed from the clayey glaciolacusrine plain that was formed beneath the Vanderhoof glacial lake. At the old glacial lake margins, these glaciolacustrine deposits take on the gently rolling topography of the underlying drumlinized basal till. This basal till forms the stonier glacial till of the Barret Soil Association.

The rolling topography of this land form is evident at the Chilco Creek study site. The rooting depth of the soils here is shallow, generally <50 cm. Plot slope is negligible, although the drainage off the study area is to the north-west via Chilco Creek.

The original stands of white spruce were clearcut logged in the early winter of 1964-65 and the site was broadcast burned in 1966. The area outside the research plots was left for natural regeneration, presumably for lodgepole pine. An interesting mix of pine and trembling aspen (*Populus tremuloides* Michx.) now occupies much of the area surrounding the trial. In fact, some of the best young pure stands of trembling aspen in the Vanderhoof District can be found in the stands adjacent to the study area. The study plots were laid out and planted in 1967.

STUDY DESIGN AND MEASUREMENT SCHEDULE

The EP 660 trial uses a factorial design. Three planting espacements (factor 1: 2 m x 2 m or 2197 sph, 3 m x 3 m or 1076 sph, and 4 m x 4 m or 637 sph) were used for each of the three species (factor 2: lodgepole pine, white spruce and Douglas-fir). This 3 x 3 design results in 9 treatment combinations per replicate. Two replicates of 9 plots were used at each installation, resulting in 18 plots per installation (Figure 1). Treatments were assigned to plots randomly within replicates.

Treatments were planted as either 11 rows by 11 row or 14 rows by 14 rows depending upon available space. However assessments were confined to the middle 7 rows by 7 rows of trees, or 49 trees per species-x-spacing-x-replicate combination. This meant that all measurement plots were surrounded by a minimum of two buffer rows and a maximum of four buffer rows planted at similar espacements. The plantation was measured in 1977 (year 10), 1982 (year 16), 1986 (year 20), 1991 (year 25) and 1997 (year 31). However, growth measurements were adjusted by 2 years (for lodgepole pine and Douglas-fir) or by 3 years (for white spruce) to account for time since germination in

PHOTOS 3, 4, & 5: Although many individual Douglas-fir grew well at Chilco Creek, most of the trees of this species have been damaged by repeated frost events, resulting in short, stunted trees with multi-leadered tops.

the nursery. Analysis of height and diameter growth for the trial was performed using a repeated measures analysis of variance (ANOVA) procedure. Basal areas (outside bark) were calculated from measured diameters using standard formula (Wenger 1984). Total tree volumes were calculated using the equations for juvenile trees from Kovats (1977).

Complete brushing and weeding of the plots and boundaries took place in 1979, 1986 and 1997. During the first measurement in 1977 the trees were not numbered. In 1982, the study trees were tagged, but many of these original tags were lost. All trees in the plots were re-tagged in 1986. However, the pattern of live and dead trees within the plots dating back to 1982 has allowed us to positively match trees between measurement years regardless of tag number.

In the fall of 1997, the Douglas-fir at the Chilco Road installation were pruned to a height of 3 m, or to 50% of their live crown height where total height was <6 m. Both pruning saws and pruning shears were used, although the shears proved ineffective for the very large branch diameters in most of the stand and were soon discarded. The pruning saws, although slower than the shears, could reach much easier to the desired 3 m height and produced a much cleaner cut and smaller branch nub. Pruning was done to allow tag numbers to be attached at breast height to tree boles with 3 inch zinc-coated box nails, and to facilitate easier site visits and measurements which were becoming difficult because of the thick tangle of branches in most plots. Prior to the pruning, the tags on the Douglas-fir were strung from the lower branches with wire. Where these lower branches have died and broken off, some tags have been lost. The lodgepole pine on site were pruned in 1986. A similar pruning operation is planned for the white spruce plots in 1998.

RESULTS

Table 1 and Figures 2 - 5 summarise the changes in heights and diameters and calculated volumes and basal areas that have been observed at Chilco Creek since establishment in 1967. Table 2 summarises the findings of the repeated measures ANOVA for changes in height and diameter with species and spacing at Chilco Creek.

EFFECTS OF SPECIES AND SPACING ON TOP HEIGHT AND QUADRATIC MEAN DIAMETERS

The most startling difference in tree growth between the Chilco Creek installation and the other two EP 660 installations (Bobtail Road and Buckhorn Ridge, Coopersmith 1997b, 1998) has been the very poor performance of Douglas-fir at Chilco Creek. Top heights and quadratic mean diameters (QMD) for this species are well below those at the latter two installations regardless of initial spacing (Top height is defined as the average height of the 10 tallest trees per hectare, quadratic mean diameter is the diameter of the tree of average basal area, Daniel *et al.* 1979). Even more dramatic than these growth differences, the rate of Douglas-fir mortality has been substantially higher at Chilco Creek than anywhere else in the EP 660 trial. Of the original 294 Douglas-fir planted at each site (49 trees/replicate x 2 replicate/spacing x 3 spacings) only 59.5% remain after 31 years at Chilco compared with 91.2% at Buckhorn and 93.9% at Bobtail after 30 years. The rate of loss observed in the Douglas-fir plots has also been steady since 1977 and is not the result of a single mortality event. All three espacements have lost substantial numbers of trees between the 1991 and 1997 evaluations (10 trees from 60 in the 2 m x 2 m espacement, 8 trees out of 76 in the 3 m x 3 m espacement and 4 trees out of 61 in the 4 m x 4 m espacement, Table 1). Patterns of mortality for the other two species were not significantly different at Chilco than they were at either Bobtail or Buckhorn.

From these data we can conclude that the Chilco installation is substantially different from Bobtail and Buckhorn with regard to Douglas-fir growth and survival. Why should this be so? The most likely answer is recurrent frost. Most of the remaining Douglas-fir at Chilco Creek show symptoms of repeated frost damage (photos 3 and 5). Some are so severely damaged that they resembled 2 m tall cabbages. Although both Chilco Creek and Bobtail Road are in the same biogeoclimatic sub-zone (SBSdw3), they differ in several important ways. The Chilco Creek study area is located in the Nechako Plain physiographic area (Dawson 1989). At 760 m mean elevation, this is an extremely flat area with little topographic relief which was formed from the bottom of the Vanderhoof glacial lake. The area's fine-textured soils and

PHOTO 6: Most of the trees at the 3 m x 3 m and 4 m x 4 m espacements had live crowns which extended to the ground This Douglas-fir was pruned following the Fall 1997 evaluation.

flat topography are very suitable for agriculture, but also highly prone to frosts. The management field guide for this site series recommends the avoidance of Douglas-fir in such areas because of the likelihood of frost damage (DeLong *et al.* 1993).

By comparison, Bobtail Road is located within the Fraser Basin physiographic area (Dawson 1989). At 840 m elevation, this area has greater topographic relief and coarser soils. Cold air pooling is less likely and frost events probably occur less frequently and with less severity than they do at Chilco. Summer drought, not frost, is noted to be a particular hazard for regeneration on site series such as those for the Bobtail Road installation (DeLong *et al.* 1993).

The stands at Chilco Creek are well stratified by species in both top height ($P<.000$, Table 2) and quadratic mean diameter ($P<.001$, Table 2). Not surprisingly, lodgepole pine contains on average both the tallest and the largest diameter trees in the plantation, followed by Douglas-fir and white spruce. The latter two species do not differ significantly in size from each other. The tallest individual lodgepole pine are now >15.8 m tall, with top heights 13.9 - 14.5 m depending upon espacement (Figure 2a). By comparison, the tallest Douglas-fir at Chilco Creek are now only 12.6 m tall as compared with individuals as tall as 26 m at Bobtail Road. Top heights for Douglas-fir are now 10.3 - 9.0 m (Figure 2c). The tallest white spruce were measured at 12.7 m with a top height range of 11.4 - 9.4 m (Figure 2b). As for both lodgepole pine and Douglas-fir, the observed height growth for white spruce was less at Chilco than it was at Bobtail.

In comparison to top heights, there were smaller differences between species for quadratic mean diameters. Lodgepole pine again had the largest quadratic mean diameters, 13.2 - 18.7 cm,

TABLE 1: Summary of the 30 year measurements for all 3 species at the Chilco Creek Installation of EP 660.
A: LODGEPOLE PINE

Year	1977			1982			1986			1991			1997		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	18	18	18	21	21	21	26	26	26	32	32	32
sample n	91	87	91	85	83	89	84	79	86	85	77	87	84	76	86
stems/ha	2040	956	592	1906	912	579	1883	868	559	1906	846	566	1883	835	559
average ht. (m) (se)	3.65 (0.24)	2.96 (0.24)	3.33 (0.24)	6.06 (0.38)	4.87 (0.38)	5.58 (0.37	8.09 (0.45)	6.96 (0.46)	7.80 (0.44)	10.66 (0.62)	9.36 (0.65)	10.28 (0.61)	12.16 (0.40)	11.49 (0.42)	12.52 (0.40)
top height[2] (m) (sd)	4.96 (0.15)	4.61 (0.21)	4.32 (0.23)	7.84 (0.41)	7.17 (0.35)	6.86 (0.26)	10.12 (0.53)	9.48 (0.44)	9.19 (0.35)	13.58 (0.55)	12.09 (0.57)	11.95 (0.51)	14.48 (0.33)	13.92 (0.49)	14.51 (0.66)
sample n[1]		60	81							84	76				
arithmetic mean diameter (cm) (se)		5.05 (0.46)	5.01 (0.40)	8.32 (0.51)	8.04 (0.52)	9.29 (0.50)	10.29 (0.65)	11.28 (0.67)	12.78 (0.64)	11.78 (0.87)	14.13 (0.91)	15.55 (0.85)	12.90 (0.90)	16.57 (0.94)	18.52 (0.89)
quadratic mean diameter (qmd) (cm)		5.23	5.16	8.51	8.67	9.58	10.49	11.87	13.00	11.99	14.59	15.83	13.19	16.99	18.71
basal area (m^2/ha)		1.42	1.10	10.85	5.38	4.17	16.28	9.6	7.42	21.26	13.96	11.13	25.74	18.95	15.37
Relative Density (RD) (ba/qm$^{d.5}$)		0.62	0.48	3.72	1.83	1.35	5.03	2.79	2.06	6.14	3.65	2.80	7.09	4.60	3.55
Reineke's SDI		77.62	47.04	338.04	166.66	124.19	467.20	262.61	195.70	586.05	356.44	271.83	674.76	449.21	351.07
Total Volume (m^3/ha)		6.08	4.51	19.71	8.60	6.86	40.14	21.11	16.96	71.73	41.04	34.29	98.14	66.86	57.25
mean annual increment (MAI) (m^3/ha/yr)		0.507	0.376	1.095	0.478	0.381	1.911	1.005	0.808	2.759	1.578	1.319	3.067	2.089	1.789
5-year periodic annual increment (PAI) (m^3/ha/yr)[3]				3.942	0.504	0.470	4.086	2.502	2.020	6.318	3.986	3.466	4.402	4.303	3.827

[1] Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2] Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. For the 4 m x 4 m plots, this average is based on the tallest 15 trees.

[3] 5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth.

depending upon espacement (Figure 3a). Douglas-fir and white spruce were both substantially smaller than lodgepole pine. The quadratic mean diameters of Douglas-fir ranged between 12.7 cm and 14.3 cm (Figure 3c) while those for white spruce varied between 9.2 cm and 14.2 cm (Figure 3b).

In contrast to the more obvious species effect observed at the Chilco Road installation, initial spacing did not have a significant effect on average height ($p<.052$, Table 2). After 31 years, there is virtually no difference in the top heights between espacements for any of the three species at the Chilco Creek installation. This reinforces the common silvicultural observation that height growth is set more by climate and soil than it is by plantation density, except at the extremes (both high and low) of stand density (Daniel *et al.* 1979).

Spacing did, however have a very strong influence on diameter growth (DBH, $p<.003$, Table 2). All three species exhibited a strong inverse relationship between diameter growth and espacement. The largest quadratic mean diameter trees for all three species were found in the lowest density 4 m x 4 m espacements, followed respectively by the 3 m x 3 m and the 2 m x 2 m plot quadratic means. This relationship has been shown for all commercial forest species in North America (Daniel *et al.* 1979).

BASAL AREA & VOLUME CHANGES OVER TIME

Since basal area is directly related to diameter, it is not surprising that the basal area development of lodgepole pine is far ahead of that of both Douglas-fir and white spruce at Chilco Creek (Figure 3). It is similarly not surprising that the highest density plots have the greatest calculated basal areas. In the highest

Table 1: Continued. B: WHITE SPRUCE

Year	1977			1982			1986			1991			1997		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	13	13	13	19	19	19	22	22	22	27	27	27	33	33	33
sample n	93	97	96	90	92	92	90	90	93	90	88	92	89	86	93
stems/ha	2085	1066	624	2018	1011	598	2018	989	605	2018	967	598	1996	945	605
average ht. (m)	1.34	1.40	1.51	2.31	2.50	3.11	3.50	3.98	4.77	4.62	5.44	6.42	6.45	7.64	8.62
(se)	(0.24)	(0.23)	(0.23)	(0.37)	(0.36)	(0.36)	(0.43)	(1.43)	(1.43)	(0.60)	(0.61)	(0.60)	(0.39)	(0.40)	(0.38)
top height[2] (m)	2.38	2.51	2.44	3.99	4.12	4.82	5.72	6.17	6.95	7.10	7.53	9.07	9.43	10.42	11.35
(sd)	(0.24)	(0.42)	(0.22)	(0.40)	(0.79)	(0.40)	(0.48)	(0.69)	(0.40)	(0.69)	(1.04)	(0.60)	(0.61)	(0.72)	(0.59)
sample n[1]				85	87	90		88							
arithmetic mean diameter (cm) (se)				2.54 (0.51)	2.98 (0.50)	4.03 (0.50)	4.39 (0.63)	5.42 (0.64)	7.22 (0.62)	6.57 (0.84)	8.42 (0.85)	10.36 (0.83)	8.83 (0.87)	11.89 (0.89)	14.22 (0.85)
quadratic mean diameter (qmd) (cm)				2.84	3.34	4.43	4.74	5.80	7.68	6.95	8.85	10.86	9.22	12.37	14.72
basal area (m^2/ha)				1.19	0.84	0.90	3.57	2.56	2.80	7.65	5.95	5.54	13.48	11.36	10.28
Relative Density (RD) ($ba/qm^{d.5}$)				0.71	0.46	0.43	1.64	1.06	1.01	2.90	2.00	1.68	4.44	3.23	2.68
Reineke's SDI				61.49	39.96	37.20	139.91	94.80	91.01	258.59	182.63	156.86	402.59	305.49	258.56
Total Volume (m^3/ha)				1.01	0.78	0.99	4.22	3.46	4.39	11.55	10.32	11.35	27.89	26.63	27.07
mean annual increment (MAI) ($m^3/ha/yr$)				0.053	0.041	0.052	0.192	0.157	0.200	0.428	0.382	0.420	0.845	0.807	0.820
5-year periodic annual increment(PAI) ($m^3/ha/yr$)[3]				0.202	0.156	0.198	0.642	0.536	0.680	1.466	1.372	1.392	2.723	2.718	3.144

[1] Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2] Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. For the 4 m x 4 m plots, this average is based on the tallest 15 trees.

[3] 5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth.

density (2 m x 2 m) plots, lodgepole pine basal area (25.74 m^2/ha) is nearly double the basal area of white spruce (13.48 m^2/ha) and two and a half times the basal area of Douglas-fir (10.09 m^2/ha).

As was observed for lodgepole pine at Bobtail Road, the rate at which new basal area is being added to the lodgepole pine plots appears to have peaked, perhaps as early as the 15 year evaluation in 1981 for the 2 m x 2 m plots (Figure 4a). This shows that the highest density lodgepole pine have fully occupied the site (probably since 1981) and are now experiencing strong inter-tree competition. The graph for basal area for these plots is curvilinear downwards, whereas all other graphs for the Chilco plots are either linear or are still trending upwards For both white spruce and Douglas-fir, there is no sign yet that their rates of basal area increment have slowed (Figures 4b and 4c). The growth of individual trees on these plots is not yet limited by inter-tree competition.

Lodgepole pine plots contain substantially greater total volumes compared with both Douglas-fir and white spruce. Average total volumes in the 2 m x 2 m lodgepole pine are now >98.1 m^3/ha compared with approximately 18.7 m^3/ha for Douglas-fir and 21.2 m^3/ha for white spruce (Figure 5, Table 1). Mean annual increments for the highest density lodgepole pine plot are now >3 m^3/ha/yr, more than five times that of Douglas-fir (0.6 m^3/ha/yr) and nearly four times that of white spruce (0.8 m^3/ha/yr). Since volume calculations utilise both height and diameter components, the greater height of lodgepole pine would on average account for the greater observed amounts of volume for this species.

Periodic annual increments (PAI's) peak before MAI's do, and it would appear that the highest density lodgepole pine stands reached their maximum PAI's in the 1986-91 period. The PAI for these plots is now approximately 4.40 m^3/ha/yr, down from

TABLE 1: Continued. **C: DOUGLAS-FIR**

Year	1977			1982			1986			1991			1997		
spacing (m)	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**	**2x2**	**3x3**	**4x4**
age from seed (years)	12	12	12	18	18	18	21	21	21	26	26	26	32	32	32
sample n	80	91	74	72	87	67	63	80	62	60	76	61	50	68	57
stems/ha	1794	1000	481	1614	956	436	1413	879	403	1345	835	397	1121	747	371
average ht. (m) (se)	0.88 (0.25)	1.19 (0.24)	1.21 (0.27)	1.61 (0.41)	2.06 (0.37)	2.22 (0.45)	2.55 (0.53)	3.12 (0.46)	3.43 (0.59)	3.68 (0.76)	4.79 (0.66)	4.95 (0.81)	5.73 (0.57)	6.87 (0.45)	6.96 (0.57)
top height[2] (m) (sd)	1.98 (0.19)	2.40 (0.43)	2.29 (0.27)	3.73 (0.27)	4.41 (0.68)	4.10 (0.57)	5.21 (0.23)	5.89 (0.77)	5.87 (0.83)	7.15 (0.60)	8.03 (0.90)	7.78 (0.94)	9.0 (0.88)	10.33 (0.83)	9.93 (0.84)
sample n[1]				39	59	48	43	67	51	49	72	58			
arithmetic mean diameter (cm) (se)				2.69 (0.86)	2.88 (0.62)	3.24 (0.87)	4.72 (1.01)	5.04 (0.73)	6.13 (1.05)	7.37 (1.19)	7.94 (0.94)	9.34 (1.19)	9.98 (1.27)	11.78 (1.00)	13.12 (1.27)
quadratic mean diameter (qmd) (cm)				3.06	3.26	3.75	5.10	5.75	6.88	8.10	8.96	10.47	10.70	12.61	14.25
basal area (m^2/ha)				0.65	0.54	0.34	1.97	1.89	1.23	5.65	4.92	3.24	10.09	9.34	5.91
Relative Density (RD) ($ba/qm^{d.5}$)				0.37	0.30	0.18	0.87	0.79	0.47	1.99	1.64	1.00	3.08	2.63	1.57
Reineke's SDI				55.44	36.35	20.75	110.18	83.09	50.81	220.37	160.86	98.20	287.13	249.04	150.51
Total Volume (m^3/ha)				0.52	0.55	0.36	2.26	2.51	1.81	8.18	8.85	6.06	18.7	21.24	13.94
mean annual increment (MAI) (m^3/ha/yr)				0.029	0.031	0.020	0.108	0.120	0.086	0.315	0.340	0.233	0.584	0.664	0.436
5-year periodic annual Increment (PAI) (m^3/ha/yr)[3]				0.104	0.110	0.072	0.348	0.392	0.290	1.184	1.268	0.850	1.753	2.065	1.313

[1]Where no sample number is given, n is the same for both average height and arithmetic mean diameter calculations. Where a second n is given, the second n refers only to sample number for the arithmetic mean diameter calculation.

[2]Top height calculations are averages of the 100 tallest trees/ha. For the 2 m x 2 m treatments, this equals the tallest 4 trees in the 2 replicates. For the 3 m x 3 m plots, the average is based on the tallest 9 trees. For the 4 m x 4 m plots, this average is based on the tallest 15 trees.

[3]5-year periodic increments are accurate for all periods except 1991-97, where PAI is estimated from 6 years worth of growth..

the maximum PAI values of 6.32 m^3/ha/yr recorded in the 1986-91 time period. The drop in PAI values signifies the point at which stands enter the stem exclusion phase of stand development (Oliver and Larson 1990). Inter-tree competition is increasing to the point that we can expect to see additional mortality. The PAI values for all other stands at Chilco Creek are still increasing. Inter-tree competition in these stands is not yet severe enough for us to expect to see density-related mortality.

COMPARISON OF STAND DENSITY INDICES AT BOBTAIL

It is often difficult to compare the growth rates of stands of different species grown at different initial densities. This problem is often tackled by using various relative density measures or stand density indices which are independent of site and age (Larson and Cameron 1986). Two of the most useful indices are Reineke's Stand-Density Index (SDI) (Reineke 1933, [in Daniel *et al.* 1979]) and Curtis' relative density (RD) (Curtis 1982).

SDI is the oldest of the indices and is probably the most commonly used in the growth and yield literature. Reineke observed that all single-species, even-aged, fully stocked stands of the same quadratic mean diameter will have approximately the same number of stems/ha regardless of site quality or stand age (Daniel *et al.* 1979). Stands will differ in the amount of time necessary to reach a given quadratic mean diameter. Better quality sites will produce trees of larger diameter faster than will poorer sites. However, when they reach the same quadratic mean diameter, they will all have the same approximate density. The relationship of the natural log of density to the natural log of quadratic mean diameter has a near constant slope of -1.605 for many forest species (Larson and Cameron 1986) and can be used to compare stands at various stages of development. SDI for a given stand is the number of trees at equivalent relative density when the average dbh is 25 cm. For coastal Douglas-fir, the maximum observed SDI is 1510 trees/ha while several species of pine ranged in SDI values from a low of 1015 trees/ha (longleaf pine [*Pinus palustris* Mill.]) to a high of 2106 trees/ha (Ponderosa Pine [*Pinus ponderosa* Doug. ex Lawson & Lawson]) (Larson and Cameron 1986).

SDI has increased steadily in all plots at Chilco Creek since the first measurements in 1977. The maximum SDI observed at the Bobtail Road site was 675 sph for the 2 m x 2 m lodgepole pine plots. This is close to the maximum SDI observed at the Bobtail Road installation (722 sph, again for the 2 m x 2 m lodgepole pine plots, Coopersmith 1998) No other SDI at Chilco is close to the values observed for lodgepole pine. The greatest SDI for Douglas-fir also occurred in the 2 m x 2 m plots (287 sph); however, these values were less than half the comparable values for lodgepole pine. Similarly, the greatest calculated SDI for white spruce (402 sph, 2 m x 2 m plots, Table 1) was also well below the SDI values for lodgepole pine.

The SDIs observed at Chilco are still well below the listed maximums found in the literature for ponderosa pine, the pine species most similar to lodgepole pine. This should mean that the stands at Chilco will continue to grow with little additional mortality due to inter-tree competition.

Curtis' relative density measurement is similar to SDI except that it uses basal area and quadratic mean diameter in its calculation. Values of RD range from 0 to 14 for coastal Douglas-fir. Like SDI, values of RD tend to increase over time, but can fluctuate widely as trees self-thin. Because very small trees can remain alive for long periods of time, they can drastically affect RD calculations. Events such as a heavy wind storms or dry summers, which tend to remove the smallest and most moribund individuals within stands, can cause very marked jumps in SDI (Larson and Cameron 1986).

The lodgepole pine 2 m x 2 m plots had the greatest RD at 7.09. For white spruce, the greatest RD was also found in the 2 m x 2 m plots at 4.44. The 2 m x 2 m Douglas-fir plots had the lowest relative density of any of the species at Chilco, with a calculated value of 3.08 (Table 1).

As for SDI, the observed RD values are still well below

TABLE 2: Summary of the repeated measures analysis of variance (ANOVA) for height and diameter growth differences for the 3 species and 3 spacings at Bobtail Road. The repeated measures ANOVA was given REPxSPECIESxSPACING means as input terms rather than individual tree data in order to get the correct error term in the model. The reported F-values and probability tests are for the Wilkes-Lambda test which is the correct F-test for repeated measures analysis. Because only lodgepole pine has DBH recorded for the 1977 measurement, the repeated measures analysis was done on the 1981-1997 data. This results in reduced degrees of freedom (df) for this portion of the analysis. Analysis for height was done with 1977 to 1997 data for all species. Because the yr x sp x spacing interaction terms for height and DBH are not significant, the regression lines for species and spacing main effects are not parallel. The linear or quadratic regression lines of best fit are shown in Table 3.

Source	Sum of Squares	df	Mean Square	F value	Probability[1]
DBH					
Year	665.018	3	221.673	398.040	0.000
Year*Species	5.786	6	0.964	6.856	0.001
Year*Spacing	21.646	6	3.608	6.010	0.003
Year*Species*Spacing	2.875	12	0.240	0.516	0.879
Error	6.633	27	0.246		
Height					
Year	503.792	4	125.948	939.770	0.000
Year*Species	30.242	8	3.780	11.186	0.000
Year*Spacing	2.390	8	0.299	2.815	0.052
Year*Species*Spacing	1.653	16	0.103	0.660	0.798
Error	3.750	36	0.104		

[1]Probabilities less than 0.05 are considered significant

the values where we would expect to see self-thinning losses due to inter-tree competition. Larson and Cameron (1986) ran a simulated thinning experiment through the Tree and Stand Simulator model (TASS, Mitchell 1975). Starting with a plot of Douglas-fir planted to 1110 sph (3 m square spacing) they thinned (by low thinning) to 361 sph at age 32 and 158 sph at age 47. At the time of the first thinning RD was 7.2. The first thinning reduced RD to 3.3. It subsequently recovered to 5.5 at the time of the second thinning, and was again reduced, this time to 2.7 by the second thinning operation.

FUTURE WOOD VALUES

One of the advantages of utilising higher plantation densities is that the live crowns of closely-planted stands lift faster than the live crowns in widely-spaced stands. The lower boles of densely planted stands will have smaller branch diameters and subsequently smaller knots when these branches die. The smaller live crown of very dense stands produces lower percentages of juvenile wood which normally translates to higher wood quality (Cannell 1985).

The crowns of lodgepole pine have lifted dramatically in the 2 m x 2 m plots at Chilco. In these plots, live crowns are now confined to crown positions 5 - 9 m above root collar. However, as density decreases, the live crown for this species increases dramatically. In both the 3 m x 3 m and the 4 m x 4 m plots there are live lower branches that start at the first branch (at approximately 2 m above root collar, the height limit of the 1986 pruning), Many of these branches now extend >3.5 m from the bole of the tree. Many branch diameters are now as large as 8 cm.

The crowns in the white spruce stands have not lifted appreciably in the first 31 years of the trial. Most trees have live crowns that extend to the ground. However, unlike lodgepole pine, most of the lowest live branches in spruce are quite small, the crowns are very columnar, and the branch diameters are not exceedingly large.

Little can be said about the effects of density on the live crowns of Douglas-fir at Chilco. Mortality has been so extensive in these plots and damage from frost to the remaining trees so widespread that little normal growth is now occurring in these plots. None of the Douglas-fir plots at Chilco has escaped this phenomenon. Very few of the individual live trees left in the installation have enough neighbouring trees surrounding them to cause the crowns to lift.

Despite the crown lift observed for lodgepole pine at higher densities, there has been little natural pruning of branches in these stands. Dead branches had to be manually pruned in order to produce clear boles.

CONCLUSIONS

- The overriding observation to take away from Chilco Creek is that this site is exceptionally poor for Douglas-fir when compared to either the Buckhorn installation or the geographically similar Bobtail installation. Substantial losses have occurred and continue to occur to the Douglas-fir at Chilco. Frost is the most likely candidate for this damage. Virtually every Douglas-fir tree on site shows recurrent damage from frost.
- There are clear differences between the 3 species in terms of height growth over the first 31 years of the trial. Lodgepole pine has performed the best of the three species, followed by white spruce and Douglas-fir, although the difference between the overall average top heights for the latter two species is negligible. The 1997 top heights of all three espacements of both white spruce and lodgepole pine were substantially taller than the equivalent 1996 top height estimates at either Bobtail or Buckhorn. It would appear that Chilco is a very good site for height growth of both lodgepole pine and white spruce. Interestingly, the largest quadratic mean diameters for these species were found at either Bobtail or Buckhorn, not Chilco Creek.
- Lodgepole pine is also the largest tree on site in terms of quadratic mean diameter. White spruce and Douglas-fir continue to lag far behind the former species in terms of diameter growth.
- The densities of trees tested at the Bobtail Road installation were not high enough to induce natural pruning in any of the three species tested. Given the target and minimum stocking standards of current planting in the Prince George Region (generally between 700 and 1600 stems/ha, Anonymous 1993), manual pruning will be necessary in most plantations if clear wood is the objective.

Table 3: Summary of regression analysis and equations of best fit for the prediction of average height at Chilco Creek. The equations can be linear or quadratic and were produced using a backward step wise regression procedure. The r^2 values is the proportion of variability observed in the data that is accounted for in the model. These equations lack a constant. This forces the lines through the origin, which is biologically more intuitive than regression lines with constants.

Effect	Level	Equation	r^2
species	lodgepole pine	$ht = 0.01\,(age^2)$	0.97
	white spruce	$ht = 0.04\,(age) + 0.01\,(age^2)$	0.98
	Douglas-fir	$ht = 0.01\,(age) + 0.01\,(age^2)$	0.96
spacing	2 m x 2 m	$ht = 0.23\,(age)$	0.80
	3 m x 3 m	$ht = 0.24\,(age)$	0.89
	4 m x 4 m	$ht = 0.25\,(age)$	0.87

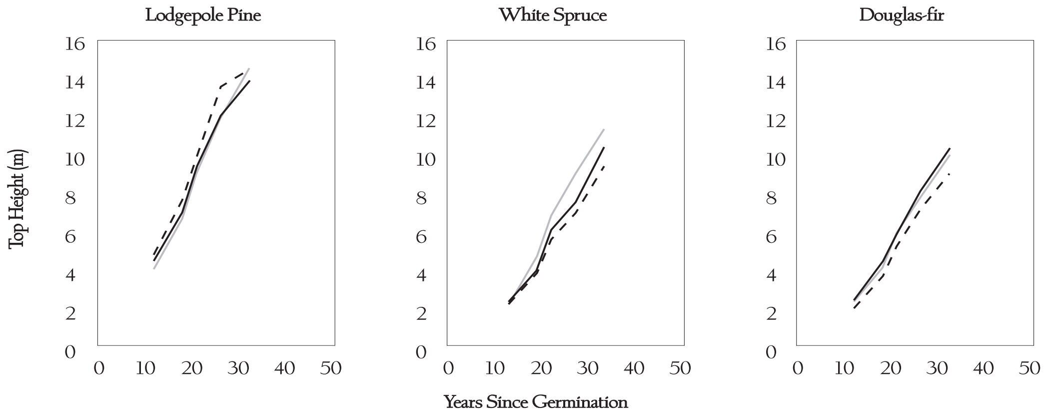

FIGURE 2. Changes in top height over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce

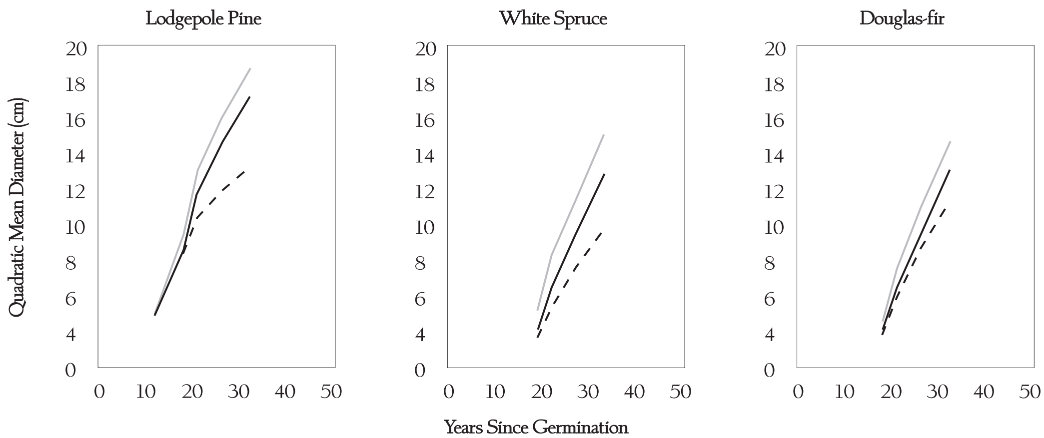

FIGURE 3. Changes in quadratic mean diameter over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

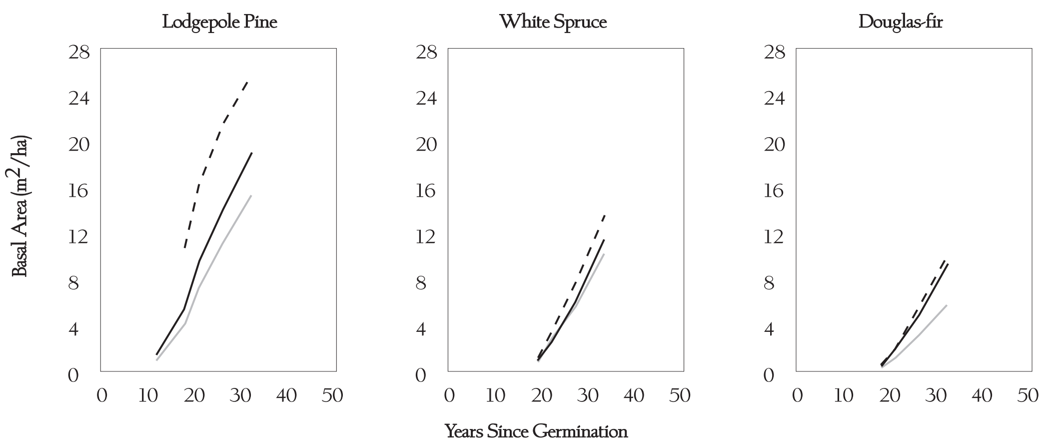

FIGURE 4. Changes in summed basal area over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

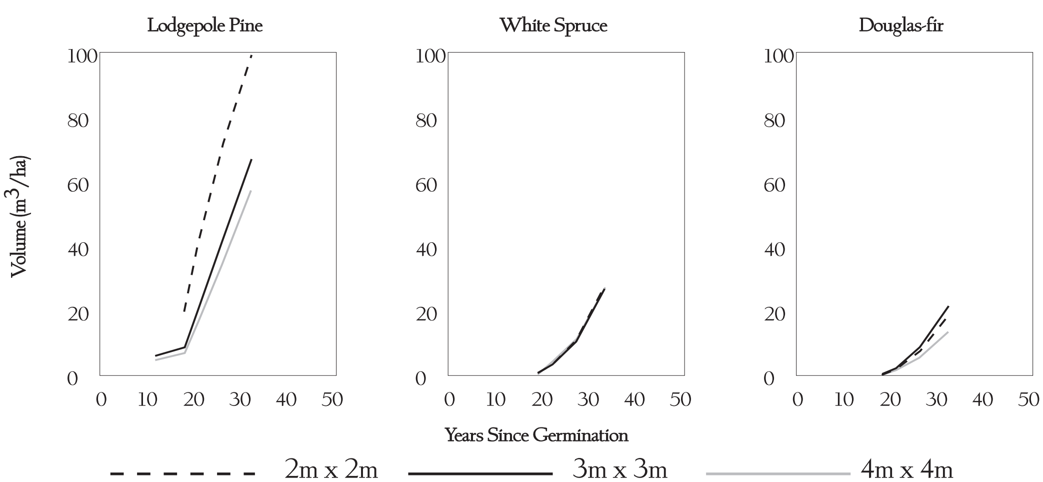

FIGURE 5. Changes in summed total volume over time at the Chilco Creek Installation for a) lodgepole pine, b) white spruce and c) Douglas-fir.

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DOUGLAS-FIR IN NORTHERN ECOSYSTEMS: INTERACTIONS WITH PAPER BIRCH

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Pathology of natural resource management: loss of system resilience when the range of natural variation in the system is reduced . . . Monocultures are the epitome (of this) . . . (Holling and Meffe 1995).

INTRODUCTION

Douglas-fir is environmentally stressed at the northern edge of its natural range, and although stable against disturbances that characterise this environment (e.g., historical fire regime since the Little Ice Age), it is particularly vulnerable to foreign disturbances (e.g., clearcut logging, rapid climate change). Maintaining species diversity may be important in stabilising the plant-soil system in northern Douglas-fir communities, and in preventing loss of system resilience (Perry *et al.* 1989). This paper reviews recent work on reciprocal interactions between Douglas-fir, paper birch, and soils. It describes how narrowly focused management policies may disrupt these self-reinforcing interactions, resulting in unexpected and unwanted outcomes.

DOUGLAS-FIR AND PAPER BIRCH IN NORTHERN ECOSYSTEMS

In northern ecosystems of British Columbia, Douglas-fir commonly coexists in seral stands with as many as six other tree species in the Sub-Boreal Spruce (SBS) Zone, and five others in the Interior Cedar Hemlock (ICH) zone. In particular, Douglas-fir can co-occur with paper birch in the Dry Hot (SBSdh), Dry Warm (SBSdw), Dry Cool (SBSdk), Moist Cool (SBSmk), Wet Cool (SBSwk) and Very Wet Cool (SBSvk) subzones of the SBS (DeLong *et al.* 1993), and in all subzones of the ICH in the Rocky Mountain Trench (Meidinger *et al.* 1988). Although the spatial and temporal distribution of paper birch is patchy in these subzones, it does commonly regenerate on newly disturbed sites (C. DeLong, personal communication). Where Douglas-fir also naturally regenerates or is planted following clearcutting, intimate and patchy mixtures of Douglas-fir, paper birch, and other tree species commonly occur. Research suggests that such diverse, mixed communities may be healthier and more resilient to disturbance than single species stands (e.g., predominantly Douglas-fir) (Perry *et al.* 1992, Holling and Meffe 1995, Simard 1996a).

Unfortunately, some of British Columbia's forest policies serve to convert our complex, multi-species forests into single species plantations in an attempt to increase their economic value and predictability. That is, they attempt to reduce variability in space and time. One of the most notorious policies is the free-growing requirement, which legislates that crop trees be unimpeded by competition from plants, shrubs or other trees (Forest Practices Code of British Columbia Act 1995). Only select conifer species are considered crop trees in British Columbia, and all deciduous species, including paper birch, are considered competing weeds (Forest Practices Code of British Columbia 1995). Application of this rule for achieving free-growing stands commonly has led to indiscriminate removal of paper birch from mixed Douglas-fir plantations in northern (E. Oneil, personal communication) as well as southern British Columbia (Simard and Vyse 1994). Holling and Meffe (1995) suggest that policies that apply fixed rules for achieving predictable, constant yields — such as the free-growing requirement — lead to systems that gradually lose resilience and break down in the face of disturbances that they previously could absorb.

RESOURCE COMPETITION

The free-growing legislation has been supported by short-term research which, in many cases, demonstrates maximum conifer growth in the absence of competing vegetation (e.g., Simard 1990, Wagner and Radosevich 1991). When performance was evaluated in terms of wood volume production, for example, Simard (1990) retrospectively showed that Douglas-fir saplings growing in the ICH zone performed best in the absence of neighbouring paper birch. Douglas-fir performance improved due to increased availability of light and soil moisture with decreased birch competition. When factors such as root disease-related mortality, biodiversity, and site productivity were also considered, however, Simard (1990) recommended retaining between 340 and 2100 birch stems per hectare within Douglas-fir plantations.

Manipulative experiments in the southern interior of BC also demonstrate that paper birch density reductions benefit

Douglas-fir growth in the short term (Simard and Heineman 1996, Mather *et al.* 1996). Nine years after paper birch was treated with glyphosate (birch averaged 11% cover), for example, stem diameter of neighbouring Douglas-fir was 3 cm larger (9.6 cm vs. 6.7 cm) than where it was growing among untreated paper birch (40% cover) (Simard and Heineman 1996). There was no added benefit to Douglas-fir, however, of reducing birch cover from 15% to 7% using a higher application rate of glyphosate (2.1 ai kg/ ha versus 1.1 ai kg/ha). These results suggest that low densities of paper birch do not negatively impact growth of Douglas-fir.

RIPPLE EFFECTS

The command-and control[1] approach to forest management (e.g., application of strict policies, such as the free-growing requirement, to control natural variation in our resource) can lead to short-term economic returns, but often results in unforeseen and undesirable consequences (Holling and Meffe 1995). For example, single species stands can be of high value (Vyse 1996), but are notoriously more susceptible than mixed stands to insect outbreaks (e.g., Alfaro *et al.* 1994; Shore and Safranyik 1992), pathogen infestations (e.g., Morrison *et al.* 1988) and to unpredicted market fluctuations (Vyse 1996). The unforeseen consequences of paper birch removal can ripple through ecosystems like dominoes (after Perry 1994). The "ripple effect" can be demonstrated with a common scenario in the ICH, where paper birch and other "weedy" species are brushed from Douglas-fir plantations that have endemic levels of *Armillaria* root disease, in order to meet free-growing requirements. When alive, paper birch is relatively resistant to infestation by *Armillaria ostoyae,* whereas Douglas-fir and other shade intolerant commercial conifers are susceptible (Morrison *et al.* 1991). Following brushing, mortality of targeted root systems increases the food-base readily available to *Armillaria ostoyae*, which switches readily between pathogenic and saprophytic strategies. This results in greater connectivity among *Armillaria*-susceptible root systems of Douglas-fir. In addition, removal of birch and other "weeds" results in greater water and light availability, resulting in enhanced growth rates of the free-growing Douglas-fir. The root systems of Douglas-fir close crown at a faster rate, and the disease vectors through the single species stand with fewer biological barriers and at a faster rate (H. Merler, personal communication). Incidence of disease-related mortality increases, structure of the ecosystem changes, and vulnerability to further perturbations increases.

Unexpected outcomes of birch removal are being measured in several manipulative experiments. For example, *Armillaria*-related mortality among Douglas-fir was 23% nine years after paper birch and associated "weeds" were brushed (manual cutting or broadcast glyphosate), and only 15% where they were left untreated (Simard and Heineman 1996). Similar trends in Douglas-fir mortality due to *Armillaria* root disease, as well as other agents, are being measured following a range of brushing treatments in species mixtures in the ICH zone of southern B.C. In PROBE installations (Simard 1993), for example, mortality of Douglas-fir three years after manual and/or chemical brushing treatments has averaged 8%, compared to only 2% where birch and associated "weeds" were left untreated. Where manual treatments result in vigorous sprouting of paper birch stumps, the *Armillaria* resistance mechanisms associated with birch roots (e.g., physical and chemical properties of bark, support of rhizosphere bacteria that are antagonistic to *Armillaria* rhizomorphs) may remain operative (Simard 1996a). Provided that unwanted conifers and broadleaves are not cut (i.e., tree species diversity is conserved), their roots systems do not die, and inoculum loads do not thereby increase, then disease incidence should not increase among remaining Douglas-fir (H. Merler, personal communication).

In the experiment of Simard and Heineman (1996), moose also unexpectedly browsed 50-70% of Douglas-fir leaders one and two years following broadcast glyphosate applications to neighbouring paper birch, and browsed comparatively few leaders in untreated control plots. Moose browsing was greater where birch was treated with glyphosate because of greater physical access to Douglas-fir leaders (height of Douglas-fir double that of neighbouring paper birch) than in untreated control plots (height of Douglas-fir half that of paper birch), and because of the herbicide impact on availability of birch. When available, healthy birch provides year-round browse to moose and other ungulates (McNichol and Timmerman 1981).

Overstorey paper birch can provide protection to understorey Douglas-fir against radiative and advective frost, but sudden removal of birch can result in frost damage. The tall canopy of paper birch can reduce frost hazard by reducing net radiative loss from the ground surface, by blocking the understorey tree's view of the cold sky, and by influencing windspeed so that warmer overlying air is mixed with cold air nearer the ground surface (Stathers 1989). In a twelve-year-old thinning experiment in southern Sweden, Andersson (1985) found that radiative frost incidence to understorey *Picea abies* was 25% when all overstorey *Betula pendula* were removed. Thinning heavily to create a sparse overstorey of 600 *B. pendula* stems/ha still resulted in 23% frost damage to *P. abies*, but retaining 1000 and 1800 birch stems/ha reduced frost incidence to 5% and 2%, respectively.

MYCORRHIZAL FUNGI: LINKAGES BETWEEN PLANTS AND SOIL

All of the coniferous and deciduous tree species in BC form symbiotic associations with mycorrhizal fungi: in return for photosynthate from their host trees, mycorrhizal fungi take up water and nutrients from the soil, provide roots protection from

1 The command-and-control approach to solving problems includes perception of the problem and implementation of a solution for its control. It assumes that the problem is well-bounded, clearly defined, relatively simple, and linear, and that the solution is likewise direct, feasible and effective over most relevant spatial and temporal scales (Holling and Meffe 1995).

pathogens, and support diverse communities of beneficial rhizosphere organisms. Each tree can form associations with several species of ectomycorrhizal fungi, and each fungal species varies in its ability to transport water, take up nutrients, break down organic nutrients, protect against pathogens, colonise different root ages, and exploit different soil types. Association with a broad range of mycorrhizal fungi provides host trees with physiological diversity, which is particularly important under stressful conditions (e.g., Douglas-fir at the northern edge of its range).

Most temperate tree species are host to several mycorrhizal fungi that are broad host-ranging (e.g., Douglas-fir and paper birch are both host to *Thelephora*), and some are host to fungi that are narrow host-ranging (e.g., only Douglas-fir is host to *Rhizopogon*). Where tree species share compatibility for different mycorrhizal fungi, they can become physically connected in time (e.g., inoculation of regenerating seedlings by parent plants) and space (e.g., hyphal linkages between plants). When logging occurs, the ectomycorrhizal hosts on a site change in species composition and age, inoculum potential decreases, and consequently mycorrhizal fungal species richness and diversity can decrease. Some of this decrease can be mitigated by maintaining a diversity of host tree species on the site following logging.

In a recent field study, Jones *et al.* (1997a) showed that diversity of the ectomycorrhizal community on two-year-old Douglas-fir root systems was higher when it was grown in mixture with paper birch than when grown in pure stands. They suggested that this increased diversity resulted from ready inoculation of Douglas-fir roots by colonised paper birch roots because of a readily available carbon supply (from birch roots), and from favourable modification of the soil, both chemically and biologically, by the presence of paper birch. Simard *et al.* (1997a) also showed that Douglas-fir seedlings with access to root systems of overstorey paper birch and Douglas-fir trees, were host to a greater richness and diversity of ectomycorrhizal fungi than seedlings that were grown in isolation. Seedlings with greater diversity of ectomycorrhizae performed better (i.e., greater net photosynthetic rate, greater height growth) than those grown in isolation of mature trees. The results of Jones *et al.* (1997b) and Simard *et al.* (1997a) suggest that maintenance of a diversity of tree species following logging, either through planting mixtures or leaving residuals, results in greater ectomycorrhizal diversity and potentially greater seedling productivity than does single species management.

Douglas-fir and paper birch have been shown to share compatibility for several mycorrhizal fungi over a large portion of their root systems (Jones *et al.* 1997a; Simard *et al.* 1997b), and thereby become physically and physiologically connected. The connecting hyphae can serve as conduits for exchange of nutrients, carbon and water between trees, and may result in reduced interspecific competition, redistribution of nutrients in patchy environments, and more successful establishment of regeneration (Miller and Allen 1992). In a mixed plantation in southern British Columbia, paper birch and Douglas-fir were shown to exchange 4 to 7% of their fixed carbon through interconnecting hyphae (Simard 1997c). There was a 2 to 6% net gain in carbon by Douglas-fir, with greater gain as Douglas-fir was increasingly shaded by paper birch. The carbon appears to have been transferred along a carbon-nitrogen concentration gradient from fully illuminated, nitrogen-rich paper birch to shaded, nitrogen-poor Douglas-fir. The results of this study indicate that paper birch and Douglas-fir interactions have more dimensions than resource competition alone, and the net effect of one species on another cannot be predicted without taking into account mycorrhizae-mediated resource sharing.

OTHER MICROBIAL ASSOCIATES

As with mycorrhizal communities, other beneficial microbes associated with seedling roots and mycorrhizae are affected by tree species composition. Active N_2-fixing *Agrobacterium rhizogenes* populations occur in the rhizospheres of both paper birch (48×10^3 g^{-1} d.w. root) and Douglas-fir (8×10^3 g^{-1} d.w. root), but populations associated with Douglas-fir are larger when it is grown in mixture with paper birch (49×10^3 g^{-1} d.w. root) than when it is grown alone (Simard, unpublished data). The higher *A. rhizogenes* populations and greater amount of current photosynthate allocated to roots of paper birch than Douglas-fir (Simard *et al.*, 1997d), help explain its greater associative N_2-fixation rates in the field (Hassett and Simard, unpublished data). Douglas-fir appears to benefit nutritionally from the presence of paper birch when the two tree species are grown in mixture, possibly through enhancement of its own rhizosphere *A. rhizogenes* populations, through turnover of birch's nutrient-rich litter (Simard and Vyse 1994), and/or through direct transfer of nitrogen from paper birch via shared ectomycorrhizal fungi (Arnebrant *et al.* 1993). When taking nitrogen availability, biomass accumulation rates and light competition into account, the FORECAST model simulates greater total yield of mixed stands (1200 stems/ha Douglas-fir and 400 stems/ha paper birch) than pure stands of Douglas-fir over several rotations (Sachs 1996).

SUMMARY

Rather than pursuing short-term, high economic returns through command-and-control practices, such as establishment of single species plantations and brushing to achieve free-growing status, management of northern ecosystems that include Douglas-fir must promote system stability and resilience. Although there is little research on Douglas-fir in northern ecosystems, work elsewhere suggests that maintaining diversity in plant and microbial communities stabilises systems and may help ensure successful Douglas-fir regeneration following disturbance. When mixed with paper birch, for example, regenerating Douglas-fir will be inoculated more rapidly and with a greater diversity of soil micro-organisms than when grown in single species stands, thereby increasing its net photosynthetic rate and productivity. In addition, damage or mortality among Douglas-fir due to frost, browsing or root disease may be minimised when it is grown in mixture with paper birch. Simard (1996b) provides some guidelines for managing composition, density and pattern in mixtures of Douglas-fir and paper birch under a variety of environmental conditions.

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PAST MANAGEMENT PRACTICES FOR DOUGLAS-FIR IN THE CENTRAL INTERIOR OF BRITISH COLUMBIA

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Douglas-fir has a long history of utilization in the Central Interior of British Columbia. Simon Fraser and John Stuart of the North West Company founded Stuart Lake post in 1806 and used Douglas-fir timbers for the construction of the first fort. The first "sawmill" in the mainland of British Columbia was at Fort St. James. In a pit saw in 1806, Douglas-fir was sawn for building logs. Mining activities in the area used Douglas-fir timbers and lumber extensively. Wood of this species was also used at Pinchi Lake Mine, with birch and Douglas-fir used to fuel the mercury melt pots.

Various sawmills (the Dean Neilson, Fort St. James, Park Bros., Tezzeron Lake, Farnes, Fort St. James, Riverbank, Fort St. James, etc.) cut Douglas-fir lumber in the Fort St. James area and trucked the rough lumber to Vanderhoof for planing and shipment on the Canadian National Railroad. When the British Columbia Railway arrived in the Fort St. James area (1967), the forest industry boomed there.

Harvesting mainly used Douglas-fir trees around Stuart Lake with bag booming of short logs on the lake to the sawmill at Fort St. James. This use of water transportation was discontinued in the early 1970s for various reasons. Harvesting was generally "unregulated" until 1953 when Public Sustained Yield Units were established with AAC and quota holders.

Arch trucks allowed skidding for up to several miles from the "beach" in the winter. This allowed harvesting of Douglas-fir stands for a considerable distance from Stuart Lake. After 1952, various silvicultural practices were applied to Douglas-fir stands (diameter limit, seed tree, mark-to -leave, mark-to-cut, shelterwood, etc.) Logging plans were required after 1956.

Silviculture marking crews used axes to mark trees. This practice was replaced by paint marking in 1954. A silvicultural marking crew was stationed in Fort St. James from 1954 to 1970. Douglas-fir bark beetle activity often influenced marking prescriptions. These 250 year old Douglas-fir trees were, for the most part, wind-firm with some windfall on sub-hygric sties. Preservation of understorey "advanced" regeneration (balsam, spruce and some Douglas-fir) was an important silvicultural goal. Creation of seed-bed (mixed mineral soil and humus) was achieved by summer logging or tractor scarification of winter-logged stands. Regeneration surveys employed variable circular concentric sub-plots (tree, advanced regeneration, poles, post-harvesting regeneration) up to 1976. After this time, "clearcut, burn and plant" replaced the partial cutting methods.

Regeneration success after harvesting of Douglas-fir was variable, and stocking types continued over several decades when seed crops occurred. Many stands cut before 1968 (IU) have acceptable regeneration; others have marginal or insufficient (NSR) regeneration. However, there has been conversion to balsam and spruce with a less than desirable component of Douglas-fir which is thrifty. Balsam may not be "on site" on some Douglas-fir sites. The balsam understorey (poles) 50 years old when logged had been heavily browsed by moose, and had rot and incipient decay in many cases. Release of the balsam understorey was good in many cases once it was free from moose feeding. Some balsam may be desirable on Douglas-fir sites for "biodiversity" and other reasons. A mosaic of Douglas-fir stands which provide shelter during winter storms and logging openings for food is high on the list for wildlife values (moose and deer). South to southwest aspects (such as Pinchi Ridge) are high priority wildlife areas for deer and moose. Douglas-fir and birch stands are ideal for deer where winter storms blow lichens from old Douglas-fir trees to snow drifts on ridge tops to provide easy access by deer.

SUMMARY

1. Many of the vulnerable 250 year old-growth stands of Douglas-fir in the Central Plateau have already been harvested. Remaining stands are under attack from bark beetle.
2. IU-logged stands of Douglas-fir have regenerated to mixed coniferous species and commercial hardwoods and have stocked over a 30 year regeneration period.
3. Stands are very important for wildlife.
4. Douglas-fir has good potential for reforestation on selected sites (warm, well-drained nutritious soils, often found on southern exposures).
5. Planted Douglas-fir has had a variable success history which may be attributed to mycorrhizal association or lack of boron. Poor bareroot nursery practices may also have contributed to failures.

6. Seed crops occur frequently (4 years) and seeds have good vigour. Effective seeding-in range is usually set at two and one half times the height of the trees.
7. Douglas-fir bark beetle is active and a silviculture strategy to reduce losses and to salvage affected "clumps" of trees is a major goal. Peeling bark from logs and stumps and timing of the removal of logs from the area, etc., are some practices which may reduce losses. Significant losses are reported (FIDS report 94-4, etc.)
8. A seed orchard for Douglas-fir for the Central Plateau is producing small quantities of improved seed. As this orchard develops, improved seed should be used when available.
9. Eagle and osprey habitats are important in Douglas-fir stands adjacent to rivers and lakes and must be preserved (wildlife, trees and large snags)!
10. Continuing development of techniques to grow interior Douglas-fir planting stock (including mycorrhizal inoculation) may result in better survival and growth in the future.
11. Thirty- to forty-year results (EP 660, etc.) indicate that Douglas-fir is a desirable species on site-specific locations considerably farther north than its present natural range. It should **NOT** be used in areas with frequent heavy wet snowfalls and "ice storms" since it is susceptible to snow break, poor form, etc.
12. **Douglas-fir must not be planted in frost pockets** as it is easily damaged by spring and summer frosts. **These cold, poorly drained soils are not suitable for Douglas-fir!!!**
13. Douglas-fir logs should be sorted and directed to manufacturing plants which can utilize them to their best advantages (timbers, plywood, sash and door factories, "added value").
14. Douglas-fir stands are "ecologically rich" and have many indicated uses. Sites with adequate moisture, temperature and nutrition are indicated. **Douglas-fir and birch mixtures are desirable!**
15. Evaluation of plantations suggests a 7 to 10 year period of free growing after planting and 15 to 25 year period after natural regeneration.
16. Douglas-fir chips were not accepted in the Central Interior pulp mills for a period of time in the 1970s. Their chemical content resulted in poor digestor yields and required extra bleach to produce "Alpha High Bright Market Pulp" (pers. comm. Jeff Marples). This discouraged the use of Douglas-fir in the reforestation program. Interior Douglas-fir has a relatively short, "brash" fibre with chemical extractives. Times and technology have changed and Douglas-fir chips are now accepted.
17. Gall aphid and other diseases and insects of young Douglas-fir stands are "reasonable" where this species is "on-site." If Douglas-fir is planted "off-site" these pests become rampant!!
18. Various indicator plants of good Douglas-fir sites are valuable in determining valid Douglas-fir sites (Maple, *Auralia*, Violets, *Lilliace*, spp., *Tiarella, etc.*) Mesic to sub-hygric sites are usually suitable.
19. Douglas-fir and birch relationships should be evaluated.

SOMETIMES I THINK SILVICULTURISTS MUST BE MORE PATIENT AND ABIDE BY NATURE'S TIME SCALES.

A SUMMARY OF PRESENT PRACTICES FOR DOUGLAS-FIR AT ITS NORTHERN LIMITS

LEISBET BEAUDRY

Most Douglas-fir is harvested by clearcutting, even-aged management in the Fort St. James, Vanderhoof and Prince George Forest Districts. In the last few years some form of reserves, either single tree or group, have been used to provide wildlife trees and seed trees. Most single tree reserves were found to be susceptible to windthrow and thence Douglas-fir bark beetles, so leaving trees in groups or choosing the dominant trees rather than intermediate trees as single tree reserves has become more prevalent. In some openings, existing advance regeneration has been retained with variable levels of blowdown and the subsequent increase of Douglas-fir bark beetle. Different site and tree factors have been the cause of the blowdown.

Short free-growing time frames and administrative costs of carrying openings has made natural regeneration too risky and planting the standard method of reforestation. In addition, natural regeneration has been unreliable with good seed years far apart (12 to 13 years). Appropriate seedbed and shelter to preserve germinants is lacking when seed years have occurred.

Since 1986, improved nursery practices have produced reliable stock. The most critical factor for nurseries is a well-aerated growing medium, achieved by using larger plug sizes, and fewer cavities per block, coarser growing medium and improved watering regimes. As with all species, different nurseries have varying reputations for producing the different types of Douglas-fir stock, and most foresters have a preference of where they want their fir grown. The problem of getting interior Douglas-fir to grow roots in the top 2 cm of the plug has not been solved, though recent trials with mycorrhizal inoculation seem promising.

A number of people are moving from the smaller 313s to the larger 415s for better survival and growth as the stock has improved aeration. More foresters need to choose 415s to get the better survival associated with improved nursery techniques. Most stock is one year old; however, there are some two year old bareroot transplants. It has been found that cold storage is tough on Douglas-fir and shorter storage results in better survival. Later sowing dates are being used to shorten cold storage periods. Quick thawing (<1 week) with immediate planting has also improved Douglas-fir survival.

Most planting of Douglas-fir occurs early in the spring, the earlier the better to avoid dry soils. Some summer planting is also being done successfully, and limited fall planting is being tried by one company. Most Douglas-fir is planted in mixtures ranging from 30 to 50% fir component to reduce losses to frost. Douglas-fir has been planted mixed with pine and spruce, with some trials using balsam and birch. Fertilization at the time of planting has not been successful due to the increased lammas growth and subsequent frost damage.

Fir is mainly raw planted; however, continuous furrows and raised microsites are also created mechanically. Disc trenching is the preferred site preparation in the Quesnel Forest District. Preferred sites to plant Douglas-fir have minimal frost. These sites are identified with the following factors: areas where Douglas-fir has been harvested, where slopes >15% (a requirement by the Quesnel Forest District), on middle to upper slopes, on medium- or coarser-textured soils and in areas with indicator species (e.g., Douglas maple, birch or mountain ash). The preferred microsite is high; some people prefer mineral soil exposure and others prefer maintaining the humus intact. The preferred planting depth is higher into the F and H layers where nutrients are available and aeration is improved, especially in clay soils.

Free growing and beyond: many sites where Douglas-fir is planted do not require brushing as the sites are usually drier and regeneration delays are minimized by immediate planting. Brushing is mostly of birch and aspen to meet the free-growing requirements; however several foresters think that the free-growing definition needs to be reconsidered, especially with current biodiversity concerns. In wetter subzones where snowpress is a problem, seedlot and seed transfer guidelines become more important as different provenances have different branching patterns and when local provenances are planted they are more resistant to snowpress. Brushing of the deciduous trees and other vegetation is done primarily with glyphosate. Douglas-fir is very susceptible to glyphosate and a good bud set is required or the buds will be damaged. There is usually some damage in sprayed plantations due to lammas growth, but most trees have recovered after two years. Due to the need for bud set there is not a window for spraying every year. Girdling of aspen in fir stands has also been effective.

Limited spacing has occurred in Douglas-fir stands. Douglas-fir responds well to release with the exception of thin, heavy crowned trees which are susceptible to snowpress. Developing a crown size to diameter ratio guideline was suggested to minimize snowpress damage. (One of the restrictions is that the spacing criteria in the Forest Practices Code guidebooks fit pine better than fir.)

Limited fertilization has occurred in Douglas-fir. Lakeland Mills has found that urea (nitrogen), sulfur and boron resulted in increased growth of fir.

Pruning has also been limited. The criteria in the Forest Practices Code guidebooks are hard to meet with existing stands. Some foresters think that Douglas-fir growth is not fast enough to warrant pruning with existing rotation lengths. However, existing information on Douglas-fir site productivity is very poor and more information is required.

Douglas-fir is relatively free of diseases. Once established, very few pest problems occur until Douglas-fir bark beetle at maturity. Douglas-fir is susceptible to whipping from a deciduous overstorey. The multiple leaders that arise from frost damage have not been found to affect tree form. Some potential problems could occur with cankers which are minimized with the current practices of planting Douglas-fir in mixtures.

As you have heard, present management practices have overcome some past challenges, but not all operational foresters are aware of these options and this forum is intended to share and discuss these ideas. This was a brief summary of present practices in the northern extremity of Douglas-fir occurrence.

DOUGLAS-FIR PROBLEM ANALYSIS

This project was initiated to review the ecology, status, trends and values of the Douglas-fir resource in the northern interior of British Columbia. The project goals were to present the review at a workshop, produce an interim management plan, and a long-term research and extension strategy. When this project was initiated, many questions were identified by foresters, licensees and other concerned people. For an introduction to the concerns about the Douglas-fir resource, the main questions were voiced as follows:

- Is Douglas-fir a diminishing component of our landscapes?
- What is the significance of the resource in our area?
- Is our database sufficient to address these questions?
- What sorts of wildlife use is there in Douglas-fir stands?
- What is the historic range of Douglas-fir and is it moving north or south?
- What silviculture systems work in what areas?
- Why do we want to maintain Douglas-fir? Why is it so valuable?
- What is required to grow Douglas-fir?
- What is the relationship between Douglas-fir and birch, if any?
- What relationships can be established between Douglas-fir and site?
- Will partial overstories provide frost protection and if so at what densities?
- What are the growth trends for Douglas-fir?
- What about slope, elevation, slope position, aspect, and soil characteristics and their influence on Douglas-fir growth?
- Does surficial geology create specific conditions conducive to Douglas-fir growth?

Some of these questions are answered with present information or current research and others we have little information on and research needs to be initiated.

REVISITING ECOSYSTEM CLASSIFICATION OF DOUGLAS-FIR IN THE SBSdw3, wk3, AND mk1 SUBZONES

LEISBET BEAUDRY AND RHIAN EVANS

The Douglas-fir problem analysis was initiated to review the ecology, status, trends and values of the resource, as well as needs with respect to research, policy and management. A portion of the problem analysis was to refine the existing Biogeoclimatic Ecosystem Classification System (BEC) within the subzones SBSdw3, wk3 and mkl by collecting additional information through releve samples. Refinement of the classification was intended to provide decision-makers with better information for operational management of Douglas-fir, particularly in the Fort St. James Forest District. In this District, the BEC classification poorly recognizes the prevalence of Douglas-fir in the landscape, and, therefore, all documents derived from the ecosystem information (e.g., stocking standards) are difficult to apply.

Refining the existing BEC classification system involved field sampling in the summer of 1996. Sampling was restricted to the SBS dw3, mkl and wk3 as these subzones represent the northern limit of Douglas-fir and are found in the Fort St. James Forest District. Sampling was also restricted to mature stands ranging in age from 80 to *150* years, considered climax ecosystems though young enough to provide accurate SI index values. A minimum 20% cover of Douglas-fir in a stand was required to ensure the existence of Douglas-fir wasn't an anomaly. The target was to sample 5 plots per ecosystem with the assumption that Douglas-fir ranged from crest to lower slope mesoslope positions. The vegetation, soils and site attributes were recorded using forms and codes from "Describing Ecosystems in the Field" to meet current Ministry of Forests standards. The vegetation was compiled using V-tab, with the standard procedures for identifying site series in the current ecosystem field guides. We then summarized the data in soil, site and plant community ecosystems corresponding to the ones in existing ecosystem guidebooks. A portion of these sites was also sampled for wildlife information which is included in the new guide.

RESULTS

New plant communities were identified with differences in soil and site factors.

ACROSS ALL THE SUBZONES:

- Douglas-fir location correlated with the presence of Douglas maple on all subzones.
- As expected, humus depth and SI increased as sites become richer and wetter.
- Douglas-fir occurred on those wetter than mesic ecosystems which had medium- and coarse-textured soils.
- Douglas-fir plant communities occur on richer nutrient sites within an ecosystem dr similar ecosystems when compared distribution information in existing guides.
- pH on Douglas-fir sites was wide ranging; higher pH was found on limestone soils so pH can be used as an indirect measure of nutrient availability.
- When using the keys to place sampled ecosystems on the grid, the soil moisture keys worked well but for soil nutrients the noted exceptions of limestone and other base-rich parent material and the presence of an $Ah \geq 5$ cm were frequently used.

SPECIFIC TO THE SBSDW3:

- Douglas fir in the dw3 also occurred with birch and Douglas maple.
- Only the 07 site series had a significantly different plant community when compared to the existing field guide for the SBSdw3. The presence of Douglas-fir, devil's club and showy aster, and the absence of mnium and mitrewort with more birch, subalpine fir, red osier dogwood and step moss led us to describe this as a phase of the existing 02 site series and a new site series name, "'Fd-oakfern," has been created.
- The 02 sites sampled included richer sites than in the existing guide. Common juniper was also noted as a common species on most sites.
- The 04 sites sampled were also richer sites; the plants were very similar but no prince's pine was noted in our plots.
- The mesic sites included slightly wetter sites than noted in the existing guide; on the sampled sites, Hooker's fairybells and red osier dogwood, sweet cicely and sarsaparilla were noted (not indicated in the existing guide).

SPECIFIC TO THE SBSMKL

- Two significantly different plant communities were identified when compared to the existing guidebook.

- The 02 site series sampled has Douglas-fir, subalpine fir, juniper and more lichen, no pin cherry, northern bedstraw or sarsaparilla and less saskatoon and rough fruited fairy bells; we have called this a new phase of the existing site series and given it a new name, "Fd-Soopolallie."
- The 07 site series sampled has Douglas-maple, Hooker's fairybells, did not contain ladyfern, one-leaved foam flower and electrified-cat's tail moss and had less Douglas -fir. This led us to create a phase of the 07 named "Fd-Douglas maple." The 08 site series did not have sufficient samples to be distinguished from the 07 site series in our data set.
- The 04/05 site series was not found to have distinctive plant communities in our sample, and the plant community described was similar to that in the existing guidebooks. The sites sampled were limited to medium and coarse textured soils, and tended to be richer.
- The mesic site was slightly wetter than noted in the field guide; the vegetation was similar with wetter indicators (devil's club, red osier dogwood and mnium).

SPECIFIC TO THE SBSWK3:

- Douglas-maple, mountain ash and birch were associated with Douglas-fir as expected.
- Douglas-fir occurs in more site series than the field book indicates; all plant communities were different from the existing site series in the field guide.
- The 02 site series was the only site series originally noting Douglas-fir; the sites sampled were richer and had Cladonia and Cladina species; no dogwood, black gooseberry, queen's cup or meadowrue were found. The 02a phase was called the "Fd-birch-leaved spirea."
- The 03 site series has Douglas-fir, birch, and Douglas-maple, less gooseberry, cranberry, false Solomon's seal and no fireweed. The site had richer nutrient status. The 03a phase was called the "Fd-step moss phase."
- The mesic site has Douglas-fir, birch and subalpine fir, Douglas maple, queen's cup and purple peavine, more thimbleberry, hooker's fairybells and devils club or *Barbilophozia* sp. The sites had a wider moisture range and included richer sites. The 0 1 a phase was named the "FdBl-purple peavine."
- The 06 site series has Douglas-fir, and birch, and Douglas maple but includes red osier dogwood and has less moss cover than stated in the existing guidebook. The sites were all medium- to coarse-textured and richer than noted in the existing guidebook. The new 06a phase is called "Fd-Douglas maple."

In summary, new plant phases need to be recognized in the SBSdw3, wk3 and mkl subzones to ensure management options for Douglas-fir are implemented. This new information allows one to identify sites where Douglas-fir can grow when Douglas-fir is not currently established. Site specific Douglas-fir management interpretations have been developed for each of the site series described.

PROBLEM ANALYSIS AND INTERIM MANAGEMENT STRATEGY

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STATUS OF THE RESOURCE

Douglas-fir is a species requiring specific attention to ensure it is maintained as an ecosystem component in the Prince George Timber Supply Area (TSA). Douglas-fir forest types comprise approximately 8% of the harvestable land base and Douglas-fir makes up approximately 4% of the cut in the Prince George TSA (Jull 1997). Douglas-fir is widely scattered on the landscape, with Douglas-fir leading types found adjacent to many of the larger lakes in the area and in areas with significant topographic relief and rich soil types. The age class distribution of Douglas-fir is relatively well balanced from 41 to 250 years of age (Table 1).

There is currently a mid-aged cohort (41 -120 years) that, if properly managed, will develop all the necessary attributes of old growth stands on the landscape for the immediate future. In the long term, there are insufficient immature and regenerating stands (0-41 years) present to maintain natural levels or the functional role of Douglas-fir on the landscape. The lack of regenerating and immature stands is likely a result of both fire suppression and stand conversion from Douglas-fir to other species once sites are logged. There are instances of stand conversion which result in changes in the dominance patterns of the stands: where once stands were Douglas-fir leading, second growth stands now contain Douglas-fir as a secondary or tertiary species.

VALUES AND SIGNIFICANCE OF DOUGLAS-FIR AND DOUGLAS-FIR ECOSYSTEMS

Douglas-fir has a number of attributes that give it a key ecological role in these northern ecosystems. Relative to other northern species, Douglas-fir can grow to tremendous sizes, lives a very long time, and has a very slow rate of decay, both while standing and as coarse woody debris. These attributes are key for maintaining above ground biodiversity of animal species and for contributing significant amounts of soil wood necessary for long term soil productivity and health (Franklin *et al* 1981, Franklin and Spies 1991). Douglas-fir's role in enhancing soil productivity is seen as perhaps its most significant contribution to the landscape; a rich, healthy soil produces forest components that contribute to a rich biological diversity and high value timber products.[1]

Because of its association with areas of rich biological diversity, Douglas-fir has been identified as a target species for retention and maintenance on the landscape in all higher level plans governing the TSA. Douglas-fir is often associated with critical habitats for a number of species in this area, including mule deer, bats, garter snakes and bushy tailed wood rats.[2] Wildlife habitat was inventoried and measurements were gathered for coarse woody debris, the number and size distribution of snags, and the levels of use noted by various species in an attempt to quantify these relationships. Douglas-fir is also a major component of a blue listed plant community found in the SBSwk3 subzone.

Cultural values for Douglas-fir centre around the high profile it takes in local land use planning initiatives. Because of the spatial distribution of Douglas-fir, it has high recreation and scenic values. Because of its ecological values, Land and Resource Management Planning (LRMP) tables have recommended a number of objectives and strategies to maintain Douglas-fir as a viable species in the Prince George TSA. In the scientific community, the Douglas-fir in this area commands a high level of interest because it is at the edge of its range and hence has a high degree of genetic plasticity.

Economically, Douglas-fir contributes approximately $12 million/year in stumpage revenues in the Prince George TSA in addition to the revenues generated by industry in selling the timber. Partial cutting strategies used to maintain non-timber values in Douglas-fir stands result in additional costs.[3] Because the stumpage system is not responsive to these costs, markets for Douglas-fir are highly variable, and many mills do not utilize Douglas-fir. It is not a preferred species in some parts of the TSA. Poor past management practices, additional costs from plantation failure and the extensive time periods required to reach free growing were seen as disincentives to establishing Douglas-fir.

1 Russell Graham, Research Forester, USDA Forest Service, Intermountain Research Station, 1997, pers comm.

2 Joanne Vinnedge, Forest Ecosystem Specialist, Ministry of Environment, Fort St. James, 1996, pers comm.

3 Les Huffman, Woodlands Manager, Apollo Forest Products, 1996, pers comm.

Table 1: Prince George TSA Douglas-fir inventory using 1989-1994 data.[4]

Age Class	DOUGLAS-FIR FOREST COVER BY DISTRICT (IN HA AND %)			
	Vanderhoof (ha)	Fort St. James*(ha)	Pr. George*(ha)	All districts (ha)
all vets	1346 4.8%	167 0.4%	4842 2.2%	6354 2.2%
leading mature (7+)	3564 12.8%	11270 26.2%	20868 9.6%	35702 12.4%
leading immature (3-6)	2006 7.2%	6411 14.9%	11611 5.4%	20028 7.0%
leading seral (1,2)	518 1.9%	173 0.4%	4740 2.2%	5431 1.9%
2˚ mature (7+)	7621 27.4%	11430 26.6%	93773 43.3%	11282 39.3%
2˚ immature (3-6)	10752 38.7%	9622 22.4%	56213 26.0%	76587 26.7%
2˚ seral (1,2)	1967 7.1%	3878 9.0%	24527 11.3%	30372 10.6%
Total ha of Fdi	27772	42950	216575	287298
Percent of total Fdi by district	9.7%	14.9%	75.3%	—

* doesn't include TFL 42 (FSJ) or TFL 30 (PG)

Plantation data gathered on sites ranging from 5 to 22 years old indicates that Douglas-fir often grows slower than lodgepole pine (*Pinus contorta* var.*latifolia*) in the first 15 years. Figure 1 illustrates site productivity and height growth data gathered as part of the problem analysis. The data indicate that on broadcast burn sites, Douglas-fir can reach 3 m green-up at 11 years, while taking 13 years on mechanically site prepared (MSP) sites (generally disc trenched), and 19 years if left to nature. Improved nursery culture for Douglas-fir, combined with the appropriate choice of regeneration strategies as outlined in this report, can result in thriving Douglas-fir regeneration and reduced time to green-up.

Published site index species conversions for lodgepole pine: Douglas-fir indicate that Douglas-fir has a lower site index at 50 years (SI_{50}) than pine (Pli) across all site indices (Nigh, 1994). Only 3 samples included in the correlation data are from subzones found in the study area, with none coming from the wettest of the subzones.[5] Our data show a trend toward increasing SI_{50} by site series as we move north into the wetter subzones (Figure 2).

Our trend suggests that the published correlations do not reflect the good productivity potential for Douglas-fir in these northern subzones. In fact, the height growth and derived site index of the 3 major species on a naturally established stand in the SBSmk1 (Figure 4) indicates the opposite of the published species conversion for lodgepole pine to Douglas-fir. More data are required to confirm these trends in these northern ecosystems.

Growth and yield curves for Douglas-fir indicate that it is more responsive to site variables than either pine or spruce (*Picea glauca x engelmannii*). On sites with a Douglas-fir $SI_{50} > 15$ m, Douglas-fir exceeds the growth potential of pine at all rotation ages >50 years, and for spruce at all rotation ages greater than 80 years (Thrower *et al.* 1991). This is illustrated graphically in Figure 3. Where longer rotations are required to meet non-timber goals, there is a significant benefit from establishing Douglas-fir, either in pure or mixed stands. Local data as indicated in Figure 4 show that Douglas-fir growth exceeds that of pine prior to the average 80-year-rotation predicted for these areas. Douglas-fir also maintains a consistently high mean annual increment (MAI) from age 70 to well over 100 years (Curtis 1993).

Thus, Douglas-fir plantations can greatly increase the potential for wood production on these sites while providing for other values if the Douglas-fir component is retained longer than 80 years. These factors, in concert with Douglas-fir's links to higher site productivity through its contribution to soil wood, make it a desirable species to manage over longer rotations in this area.

4 The data for Table 1 was derived from the interior Douglas-fir study conducted in 1994 for the Prince George TSA. Estimates on the age of the inventory data used for the 1994 study indicate that the inventory files were updated between 1989 and 1994.

5 Pat Martin, Stand Development Forester, Silviculture Practices Branch, Ministry of Forests, 1996, pers. comm.

CURRENT MANAGEMENT PRACTICES

Currently, bark beetles are in charge of management actions, both as a result of the extensive time frames required to move from detection to harvest and because of the choice of management regimes. The Douglas-fir bark beetle epidemic in the Fort St. James District has focused the attention of managers on the difficulty and expense of maintaining mature stands in a state that is out of balance with the natural ecology of the area. The ecosystem evolved in response to relatively frequent fire events. Because of fire exclusion in the past 60 years, many of the Douglas-fir stands in the area now have extremely high stocking. High stocking in combination with a recently ended 10-year-growing season drought has stressed these mature stands, increasing their susceptibility to bark beetle infestation. Current management practices focus on either minimal harvest of Douglas-fir in some areas, or clearcut harvest of beetle-infested stands. Current management focuses on thinning from above or clearcutting to remove the high risk stems from Douglas-fir stands. Such managment is exactly contrary to the natural regime of thinning from below that results from a frequent fire history.

Current management practices have a number of risk factors inherent in them. Deferring harvest or logging without a management strategy allows the bark beetles to dictate management actions. It also limits our options with respect to silviculture systems, increases gaps in the age class distribution, does not allow higher level objectives to be realized, and in the long term, may well result in a loss of biodiversity.

GOALS AND STRATEGIC DIRECTIONS

Key concepts essential in managing Douglas-fir in these northern ecosystems are outlined in Table 2. Goals and strategic directions for Douglas-fir management must start with a landscape level plan, preferably by resource management zone (RMZ). Landscape level planning steps include determining the extent of Douglas-fir within the landscape unit, chart or RMZ, determining reference conditions for the area, and determining management objectives that include both a spatial component and a temporal component. Once goals for the unit are set, areas should be evaluated for risk factors such as beetle infestation and windthrow. Additional steps should be outlined to maintain special sites, and suitable silviculture systems chosen to meet short and long term goals for the areas.

Silviculture systems other than clearcutting are recommended to meet the multiplicity of objectives and maintain the values associated with Douglas-fir stands. Of particular import is the need to beetle-proof high risk stands by reducing stocking while maintaining the large trees and coarse woody debris thought to be key attributes necessary for wildlife habitat and biodiversity. Beetle-proofing activities are especially critical along the south aspects of many of the larger lakes in the Fort St. James area ; these are key wildlife habitat areas, and contain significant scenic value. A focus on regenerating more Douglas-fir than is harvested is recommended, at least in the short term, to make up for the shortfall of regeneration in the past 2 to 3 decades. Regenerating more Douglas-fir than is harvested will meet the LRMP goal of maintaining natural levels of Douglas-fir on the landscape. The additional regeneration effort can be concentrated on areas which contain many of the attributes found in association with Douglas-fir stands at present.

The goal of maintaining Douglas-fir on the landscape requires some administrative changes. Of most import is a revision to the biogeoclimatic ecosystem classification (BEC) for the SBSdw3, SBSmk1 and SBSwk3 to include Douglas-fir in a number of site series where it is currently not recognized. Concurrent with these changes to the ecosystem classification scheme, it is necessary to include Douglas-fir as an acceptable species in the site series where it is found in the FPC Establishment to Free Growing Guidebook. Free growing definitions (where Douglas-fir is found in association with birch) should be revisited, as there is considerable evidence that the two species are mutually beneficial. Issues around seed planning should also be revisited to determine our precise seed requirements and develop a suitable cone collection strategy to meet all management needs in the area.

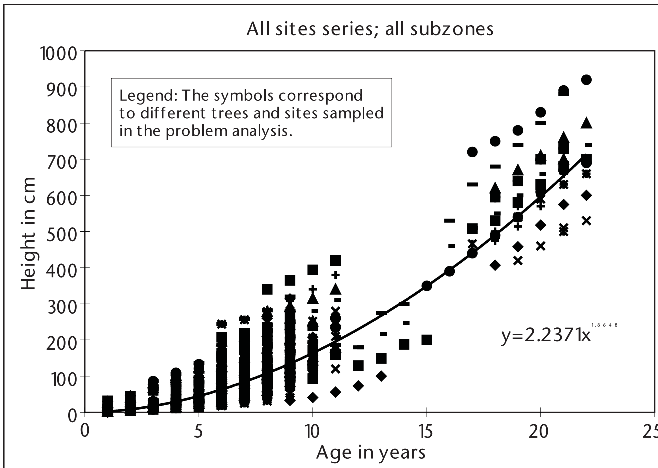


FIGURE 1: Douglas-fir growth from plantation establishment to free growing (1-22 years).

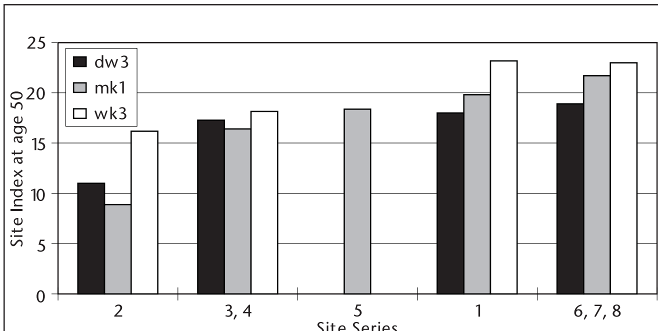


FIGURE 2: Comparison of Site Index of Douglas-fir across the SBSdw3, mk1 and wk3.

REGENERATION, RECRUITMENT AND RESTORATION

For regenerating Douglas-fir, a number of critical factors must be considered. Chief among them is choosing a future stand structure that will meet the majority of landscape level goals, and then determining which silviculture system can best achieve that stand structure. Partial cutting regimes are recommended as they can be used to meet a number of landscape level objectives while still providing timber values.

When retaining overstorey trees in partial cutting regimes, consider both site variables and tree characteristics that are most likely to result in minimal losses to windthrow and bark beetles post harvest. When prescribing partial cutting regimes for Douglas-fir harvest in high beetle risk areas, it is essential to beetle-proof stands to ensure that the desired number of retained stems will remain. Beetle-proofing includes such factors as choosing the most vigorous trees for leave tree(s), and prompt slash disposal. Using prescribed fire as a slash disposal tool and to beetle proof stands is highly recommended.

Though partial cutting regimes are preferred, all silviculture systems can be successful in regenerating Douglas-fir in this area. Because of existing stand structures, some silviculture systems will take a number of entries to meet a particular goal.

Because of administrative limitations such as free growing time frames, regeneration strategies for Douglas-fir should focus on artificial regeneration. Douglas-fir excels on rich, frost-free, well-drained sites. Aeration, both while growing in the nursery and once out-planted, is one of the key requirements for successful regeneration. In addition to aeration, for Douglas-fir to excel, a rich soil substrate is required. This rich soil substrate can take the form of rotten wood, humus, or base rich mineral soils such as weathered limestone. Site preparation strategies should ensure that aeration, soil wood, and organic layers are retained. Mounding and broadcast burning are suitable site preparation techniques. Machine piling often results in a significant loss of organic material, and is not recommended. Douglas-fir is often found in association with birch. There are indications that Douglas-fir and birch form a symbiotic relationship and share resources through their mycorrhizae. Douglas-fir is more susceptible to frost damage than other tree species in this area. Because of frost issues and the mutually beneficial relationship between Douglas-fir and birch, it is recommended that brushing be minimized on sites with birch competition as long as the Douglas-fir is maintaining adequate leader growth.

WHAT'S NEXT?

The problem analysis has pointed to a number of initiatives that are required to maintain Douglas-fir in our northern landscapes. Key in these initiatives is the need to coordinate a timber harvest strategy, develop training packages for partial cutting harvest operations, leave- tree selection and marking, and plantable spot selection for Douglas-fir.

Further research requirements include studying:

1. The relationship between Douglas-fir ecosystems and wildlife species of concern.
2. Douglas-fir/birch dynamics.
3. Site index correlations with other tree species.
4. Douglas-fir's role in maintaining biodiversity and soil productivity.
5. The role of renewal agents (fire and bark beetles) in Douglas-fir ecosystems.
6. A comparison of Douglas-fir growth dynamics in pure and mixed plantations.
7. The requirements for successful natural regeneration
8. Stand reconstruction studies and identification of traits that contribute to the survival of veteran Douglas-fir.

Key concepts, rationale and recommendations for Douglas-fir management are outlined in Table 2. These concepts flow from two basic theses. First, that Douglas-fir and Douglas-fir ecosystems are sufficiently special to demand the additional management attention they require; and second, that Douglas-fir stands must be managed within the context of landscape processes.

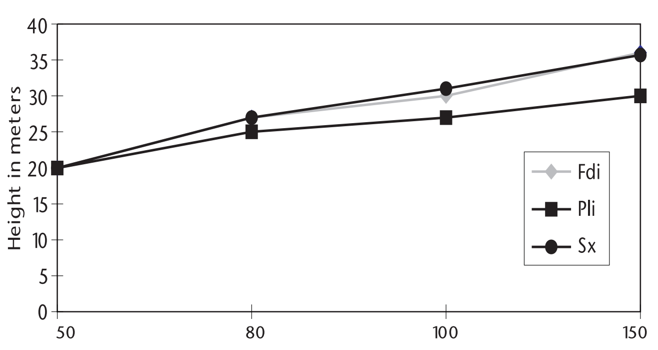


FIGURE 3: Douglas-fir, lodgepole pine and spruce growth trends at SI_{50} of 20.

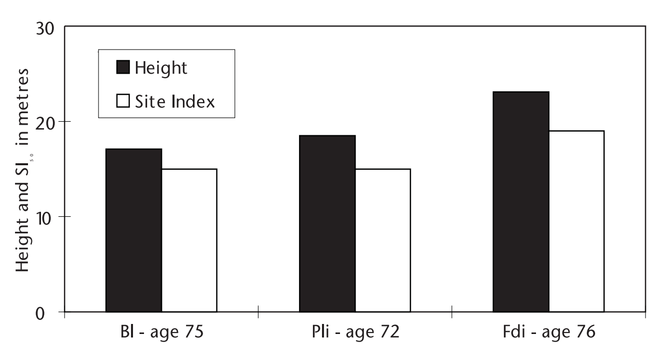
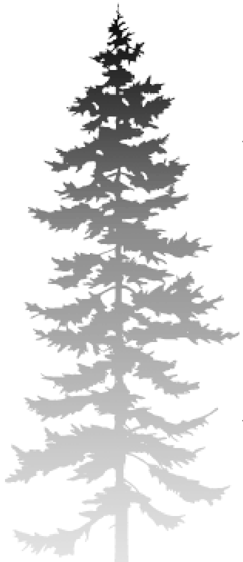


FIGURE 4: Jumping Lake 2nd Growth: height and site index comparisons.

TABLE 2: Key Concepts for the Management of Douglas-fir (Fdi) in the Prince George TSA

KEY CONCEPTS	RATIONALE	RECOMMENDATIONS
Landscape Level Planning	Stands managed in isolation without the benefit of a succinct landscape level plan will not give a pattern suitable for the myriad of users of Fdi and Fdi ecosystems.	Determine target levels of Fdi for the RMZ to set the stage for stand level management. Plan for active management intervention in specific areas to ensure long term retention of old growth attributes. Intervention will take the form of beetle proofing high risk stands.
Ecological role	Fdi is a unique because it grows so large, lives so long and takes so long to decay relative to other tree species in our landscapes. These factors make Fdi key in maintaining below ground soil function and above ground biodiversity.	Maintain a Fdi component in all areas it currently exists. Plan to retain a component of the largest Fdi in all stands where it occurs for wildlife trees, CWD and ultimately soil wood.
Productivity	On medium to good sites and rotation ages > 50 years, Fdi is the most productive species found in these northern ecosystems. Fdi enhances site productivity through its function as coarse woody debris and soil wood.	Promote the development of mixed and pure Fdi stands for maximum timber yields. Retain a % of Fdi component past early rotation age for a higher value product mix. Retain a Fdi component into future rotations to serve as snags, coarse woody debris, and soil wood.
Silviculture systems	As Fdi plays a number of significant roles in these northern ecosystems, it is as valuable standing as it is for timber production. Natural disturbance regimes have given us a legacy of two aged stands which are suitable for a number of partial cutting regimes.	Focus on partial cutting regimes that mimic natural disturbance patterns. Retained stems should be chosen on the basis of tree <u>and</u> site characteristics for optimum results. Focus on developing stand structures that contain large remnant stems and are resistant to bark beetle infestation.
Site requirements	Fdi excels on rich well aerated sites, but is prone to frost damage. Establishing Fdi on sites that meet the following criteria will result in successful regeneration within time frames that are comparable to that of pine and spruce.	In areas of bark beetle risk, reducing beetle brood habitat through prompt slash disposal is paramount. Focus on leaving soil wood and humus layers intact during all management operations. Ensure good soil aeration. Plan to minimize frost damage through choice of site and/or the use of nurse crops of pine and birch.



WORKSHOP SUMMARY: RESEARCH THEMES EMERGING FROM THE DOUGLAS-FIR PROBLEM ANALYSIS

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One result of the Douglas-fir problem analysis generally, and of the workshop specifically, is that we now have better information to classify and identify sites containing (or capable of supporting) Douglas-fir. We also have a better basis for understanding Douglas-fir as an ecological component of central interior landscapes.

In addition, the problem analysis brought out some interesting and potentially important themes that should be explored in future research.

Up here, Douglas-fir is not what we thought it was. At the workshop, we heard from several practitioners who complained that Douglas-fir is a difficult species to manage in the central interior because it does not "follow the rules." We also heard silviculture professionals attribute Douglas-fir failures to certain "myths" about its ecology and regeneration (example: Douglas-fir needs mineral soil for regeneration). And, we learned from research scientists that Douglas-fir exhibits some remarkable traits that might be adaptations to less-than-ideal growing sites (example: Douglas-fir requires "brown cubicle crap" to get established; and young Douglas-fir trees carry out underground exchanges of nutrients with paper birch and possibly other species).

These insights into Douglas-fir ecology may explain why its tendency to not "follow the rules" often leads to regeneration failures and other problems in central interior forests. Whereas researchers have found that the species requires organic matter (brown cubicle crap), the rules say that scarification is an appropriate site preparation treatment. Whereas researchers have found that Douglas-fir exchanges resources with paper birch and other "friends," the rules call for removal of competing brush around Douglas-fir seedlings.

Evolutionary biology theory would suggest that Douglas-fir would be more "plastic" in its environmental responses at the extremes of its range, reflecting a greater capacity for variability in genetic expression. Perhaps that is why the management practices developed elsewhere, in the more central parts of Douglas-fir range, yield unsuccessful results in the northern extremes of its range. The more that is known about these biological properties and relationships, the better position we will be in to regenerate Douglas-fir and to manage it as a component of central interior landscapes.

Douglas-fir stands may be "winking out, " irrespective of the harvest. Whenever practitioners spoke about Douglas-fir problems in the central interior, it almost always involved the Douglas-fir beetle and other forest health problems. In large measure, Douglas-fir "management" consists of sanitation and salvage activities. Managers respond to insect infestations or high-risk situations, and harvest Douglas-fir to contain the spread of the problem.

If Douglas-fir is disappearing as a landscape component in the central-interior, it is not just a matter of reducing the allowable cut of this species or even of placing a moratorium on its harvest. Management of the species appears to be primarily a forest health issue. Even if harvesting was halted tomorrow, Douglas-fir may still be at risk as stand after stand succumbs to insect infestation.

It is clear that the insects and Douglas-fir co-existed for long periods of time, as evidenced by mutual adaptations such as pheromone attractants. What was the nature of the relationships that allowed the species to co-exist, and how has that balance been disrupted in the landscape today? What is the role of fire and other renewal agents in the system? Developing understanding of these dynamics will be an essential part of any management strategy aimed at the health and sustainability of Douglas-fir and of central interior landscapes in which the species is an integral component.