Interior Douglas-Fir And Selection Management

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ABSTRACT

The Interior Douglas-fir (IDF) biogeoclimatic zone of British Columbia is a relatively hot and dry zone which supports uneven-aged forests of Douglas-fir (*Pseudotsuga menziesii* var. *glauca)*. Important to wildlife, range, recreation and timber production, these forests have been harvested by selective logging for as long as 100 years or more. Natural disturbance patterns consist of frequent low-intensity fires which maintained the forest in an open uneven-aged condition. Across this zone, however, the fire frequency has been reduced since European settlement. The result has been invasion of grasslands by forests, increasing stand density, reduced stand vigour, and increased damage by insects and diseases. Selection management appears to present an opportunity to mimic natural disturbance patterns by using frequent low-intensity harvesting entries. Selection management requires:

1. ongoing or pulse regeneration associated with each harvest entry;
2. stocking control in all size classes, including the submerchantable sizes;
3. explicit regulation of stand structure by setting residual basal area, maximum diameter, and a diminution quotient (BDq); and
4. marking of trees to guide fallers.

The history of management in the dry-belt has been unsatisfactory. Failure has resulted from highgrading, destruction of stand structure, and dysgenic selection. Changes in policy, legislation, and practice over the past 20 years have improved management significantly. Further improvement is required, however, specifically with respect to stocking control, stand structure regulation, and marking.

An extensive review of the literature dealing with the silvics of interior Douglas-fir, ecological theory as it applies to the species, natural disturbance regimes in the IDF, and selection management is presented. The theory drawn from the literature is interpreted as a basis for implementation of selection management for interior Douglas-fir in British Columbia. The operability of uneven-aged IDF forests is discussed, and management interpretations are offered.

CONTENTS

TABLES

FIGURES

INTRODUCTION

Interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.)Franco) is a wide-ranging species with a very broad ecological amplitude. In the dry parts of its range, it grows in an uneven-aged fire-dominated sub-climax. On the basis of its natural condition, the species is well managed under an uneven-aged management regime.

The Interior Douglas-fir biogeoclimatic zone (IDF) of British Columbia "...dominates the low- to mid- elevation landscape of south-central interior British Columbia..." and extends into Alberta, Montana, Idaho, Oregon and Washington (Hope et al. 1991). The IDF covers approximately 5% (4.3 million hectares) of British Columbia (Ministry of Forests 1994). Also described as the “dry-belt”, the zone has a continental climate with warm dry summers and cool winters. Mean annual temperatures range from 1.6 to 9.5°C, and annual precipitation ranges from 300 to 750 mm. The zone is dominated by Douglas-fir. Because these forests are typically dry, they grow slowly.

High-quality timber and proximity to highways and manufacturing plants make the Douglas-fir forests of the IDF highly desirable for timber harvesting. Their low elevation and limited snow pack make the forests important winter habitat for mule deer (Armleder et al. 1986), and the forests are also used for cattle grazing. Their proximity to population centres make dry-belt fir forests important for public recreation. Such multiple demands on the land base yield complex forest management objectives, and these objectives direct our prescriptions for forest management.

The history of harvesting in the dry-belt has seen primarily highgrading. The period of highgrading has left a legacy of degraded stands which are afflicted by insect and disease problems.

Starting in the late 1970’s, harvesting began to shift towards the classical European model of selection management. Selection management is a form of irregular or uneven-aged management (Province of BC 1995a) which:

- creates and maintains at least three distinct age classes;
- harvests timber at specified repeated intervals which encourages frequent establishment of regeneration in canopy gaps;
- harvests single scattered trees or small groups of trees;
- harvests in all size classes at each entry to meet and maintain specified stand structure goals.

Adoption of the methodology has resulted in the creation of guidelines by the BC Ministry of Forests (SIWG 1993). These guidelines, however, stop short of full adoption of the selection method, since some key components are not included.

Partial cutting of all types only accounted for 14% of the area harvested in British Columbia in 1992/93 (Ministry of Forests 1994). Introduction of the Forest Practices Code in 1995, however, has caused a renewed interest in all types of partial cutting throughout the province, and selection management will continue to be used with increasing frequency.

While it is widely recognized that European methods cannot be neatly transplanted to the British Columbia landscape, the theory and philosophy of the methods are applicable (Weetman 1995). There are examples in BC and eastern Canada, as well as many in the US, of forests managed according to variations of the classical selection method.

This paper presents an extensive review of the literature dealing with interior Douglas-fir, ecological theory as it applies to dry-belt Douglas-fir, and the selection method. The history of harvesting in the dry-belt is described, and management implications are discussed. Further research needs are detailed.

LITERATURE REVIEW

Silvics Of Interior Douglas-fir

Range

Interior Douglas-fir has the greatest latitudinal range of any commercial conifer of western North America (Hermann and Lavender 1990; Van Hooser et al. 1991), and the broadest ecological amplitude of any western tree (Arno 1991).

The principle limiting factors on the range of Douglas-fir are low temperatures and moisture stress. Low precipitation and high evaporation limit the distribution of interior Douglas-fir in the Rocky Mountains (Hermann and Lavender 1990; Arno 1991). In the northern part of its range, IDF is limited by cold, especially growing season frost. In dry ecosystems such as the Interior Douglas-fir zone (IDF) of British Columbia, Douglas-fir is the climax species (Arno 1991; Hope et al. 1991). Interior Douglas-fir grows in extensive pure stands, both uneven-aged and even-aged (Hermann and Lavender 1990).

Reproduction

Flowering occurs in May and June in Northern Idaho (Hermann and Lavender 1990). Seedfall occurs in mid-September, with seed quality declining rapidly during winter and spring (Hermann and Lavender 1990). The majority of seeds fall within 100 m of a seed tree or stand edge (Hermann and Lavender 1990).

In studying germination and survival of interior Douglas-fir in the IDFww and the SBSdw1, Burton (1996) found that "... moss is a universally poor seedbed, while rotten wood is generally the most superior, supporting germination and survival levels better than mineral soil in many instances." Ryker (1975) found that natural regeneration of Douglas-fir was better on litter-covered seedbeds than on mineral soil. Some level of canopy retention promotes superior germination and survival in all climates tested (Ryker 1975; Burton 1996). In drier ecosystems, regeneration is generally poor (Hermann and Lavender 1990).

Growth

Throughout its range in British Columbia, Douglas-fir ranges from very shade tolerant to very shade intolerant (Province of BC 1995b). It most-often occupies dry to fresh soil moisture regimes and medium to rich soil nutrient regimes (Province of BC 1995b). Interior Douglas-fir in the IDFdk3 subzone near Williams Lake, B.C. is classed as moderately shade tolerant (Chen et al. 1995). Douglas-fir is sensitive to growing-season frost, and a risk of frost damage exists on all subzones of the IDF in the Cariboo Forest Region, especially in lower topographic positions (Province of BC 1995b).

Hermann and Lavender (1990) and Arno (1991) describe interior Douglas-fir as a climax species in dry habitat types, and suggest that in those habitat types it is suitable for true selection management.

Arno (1991) describes a classification of environments based upon moisture regime and temperature gradient which defines the habitat types which will support Douglas-fir as a climax species as compared to those types where Douglas-fir will be a seral species. In Arno's (1991) discussion, he shows Douglas-fir as a climax or potential climax species on habitats ranging from moist and warm to cool and dry. Figure 1 below describes this relationship graphically.

Stand growth varies widely in response to biogeoclimatic conditions and genetic control (Monserud 1987; Arno 1991). Arno (1991) quotes mean annual increment capabilities of 0.7 to 7 m^3/ha/yr depending upon habitat type.

Douglas-fir responds well to thinning, but trees which have grown in a closed stand develop very slender form and short crowns, and are therefore susceptible to damage by snowbreakage and windthrow (Hermann and Lavender 1990).

Genetic Resources

Interior Douglas-fir displays a great deal of genetic variability, with clinal patterns of variation in traits observed over latitudinal, longitudinal, and elevational transects (Hermann and Lavender 1990). Variation also occurs between populations within local regions (Hermann and Lavender 1990) in adaptation to environmental gradients (Rehfeldt 1991). Variability remains high within populations (Rehfeldt 1991).

Gap Dynamics

Disturbance

Bazzaz (1983) defines disturbance as "a sudden change in the resource base of a unit of the landscape that is expressed as a readily detectable change in population response." Disturbance of forests results from many different events, both biotic and abiotic. From a single branch falling to large-scale catastrophic wildfire, disturbance affects the number,

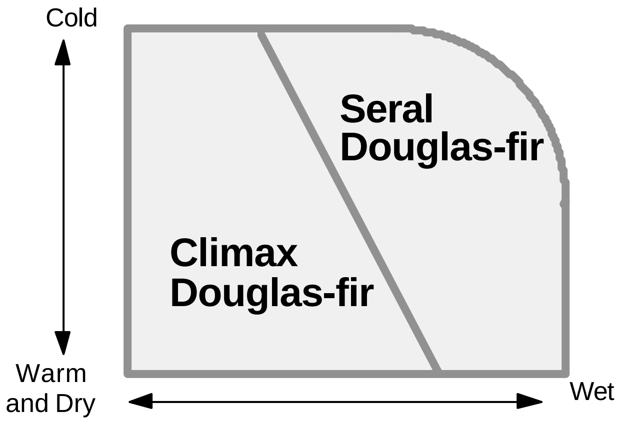

Figure 1: Impact of climate on the ecological niche of Douglas-fir. (Adapted from Arno 1991.)

species, and vigour of plants growing in an ecosystem. A wide range of sizes, intensities, timing, and types of disturbance yield a mosaic of forests on the landscape (Bazzaz 1983). Hunter (1990) describes patterns of disturbance as the most important cause of spatial heterogeneity.

Stand productivity is dependent on disturbance because disturbance controls leaf area index (LAI) and recycles biomass accumulated in the ecosystem (Waring and Schlesinger 1985). Disturbance reduces LAI by causing mortality of individual plants, and lower LAI increases growth efficiency of individual plants. High LAI's result in high gross production at the stand level, but when LAI's exceed a threshold level, net production decreases due to higher mortality (Waring and Schlesinger 1985). Therefore, as LAI continues to increase in the absence of disturbance, growth efficiency of individual trees falls, as does net production at the stand level.

Efforts at controlling disturbance prevent one kind of mortality from occurring, but increase the risk of another type of disturbance (Waring and Schlesinger 1985). In the absence of disturbance, competition increases, and growth efficiency decreases. Individuals become so limited by resource availability that few reserves are available for protective responses. Disturbance will inevitably occur, and modify the stand structure. If the frequency of disturbance has been reduced, forests are more susceptible to normal catastrophic disturbances (Waring and Schlesinger 1985).

Disturbance is characterized by four interacting features: size, intensity, frequency and type. The interactions of these features influences the response of plant populations to the disturbance (Bazzaz 1983).

Size

In all landscapes small-scale disturbances greatly outnumber large-scale disturbances (Bazzaz 1983; Hunter 1990; Guldin 1995). Guldin (1995) describes small-scale disturbance (one to several trees dying) as a basic element of stand development which adds ecological complexity.

Small gaps are generally more homogeneous than large gaps, and gap homogeneity and size interact to determine size and identity of plant populations (Bazzaz 1983). Heterogeneity within a disturbance will result in heterogeneity (e.g. clumpyness) in the vegetation (Bazzaz 1983).

The size of the disturbance directly affects the manner by which the resulting space is occupied (Bazzaz 1983). Small canopy gaps, such as might be created by a single tree fall, may be completely occupied by extension of adjacent crowns, or available space may be occupied by colonization by shade-tolerant species (Bazzaz 1983). The size of disturbances is relative to the site productivity, since more productive sites have more vigourous residuals which are able to occupy relatively larger gaps (Oliver 1995). Large disturbances are re-occupied by dispersal, establishment, and growth of colonizers (Bazzaz 1983).

The size of the disturbance therefore has a significant impact on species composition. Large gaps favour intolerant and mid-tolerant species, while small gaps favour mid-tolerant to tolerant species (Guldin 1995). Gap size is also critical to the structure of the forest (Hunter 1990). Small gaps may not result in introduction of a new cohort, if adjacent residuals take up the newly available space (Oliver 1995), and vertical homogeneity is retained. Very large gaps may have protracted stand initiation phases which result in a vertically heterogeneous stand (Oliver, 1995).

Intensity

Intense disturbances cause more mortality in a plant community than less severe disturbances, but intensity of the disturbance is relative to the autecological characteristics of the species present in the stand (Bazzaz 1983).

Intense disturbances initiate new forests and re-initiate succession of a stand. Low intensity disturbances tend to maintain a stand in one successional stage (Province of BC 1995c). Oliver (1995) discusses the impact of non stand-replacing (partial) disturbances. He states that:

> "A multiple cohort stand can result from the destruction of very few or most of the overstory trees, from the destruction of very few or most of the understory trees, or a combination of the two."

Partial disturbances therefore increase structural diversity, but probably diminish species diversity (Bazzaz 1983). A smaller guild of species are capable of establishment in a partial disturbance compared to a stand replacing disturbance (Guldin 1995; Oliver 1995).

According to Waring and Schlesinger (1985), low intensity disturbances cause a reduction in leaf area and result in increased insolation and rainfall reaching the forest floor. Soil temperatures increase, and transpiration decreases. A release of biomass (in the form of ash, leaf fall or frass) results in a flush of nutrients. Microbial activity and mineralization of available nutrients increase, and photosynthetic activity increases. Changes in leaf chemistry include better production of antifeedants. Remaining trees after partial disturbance benefit from better moisture status and fertility, and are less susceptible to herbivory and pathogens. Improvement in growth after disturbance may last decades (Waring and Schlesinger 1985).

Frequency

Frequency and size of disturbance are linked, in that small-scale disturbances generally occur more frequently than large-scale disturbances (Bazzaz 1983). Hunter (1990) suggests that the greater frequency of small disturbances gives rise to a roughly equal area of disturbance by size classes. Most stands are long lived in relation to the return period of large disturbances (Oliver 1995).

Frequency and intensity of disturbance may interact to control the primary productivity of an ecosystem (Bazzaz 1983). Bazzaz (1983) uses the example of grazing wildebeest in the African Savannah which control the primary productivity of those grasslands. It seems logical to me that similar conditions could exist in forests which burn relatively frequently at great intensity, such as the Chilcotin Plateau. Wei and Kimmins[1] have shown that productivity is strongly related to large woody biomass remaining in contact

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[1] Xiao Wei and Hamish Kimmins. Unpublished results presented in Williams Lake, May 27 1996.

with the soil after disturbance. Frequent intense disturbance by natural fires maintains this biomass at low levels.

All species have natural adaptations for recovery from disturbance; as disturbance frequency increases, some species are eliminated while others are favoured as different adaptations come into play (Reimers 1983). A reduction in fire frequency in the Great Smokey Mountains National Park has resulted in the loss of pine types which naturally dominate the dry ridges under the influence of forest fires. As the existing pine stands age beyond the natural fire period, they are being replaced by more tolerant oaks (Weinstein and Shugart 1983). Bark beetles are implicated as an agent of that change.

Succession

Discussion and description of succession has been ongoing since before Thoreau first coined the term in 1863 (Spurr and Barnes 1976). A rich and confusing lexicon has arisen throughout the study of succession.

Succession is the process by which one community replaces another as time since disturbance increases (Kimmins 1989). The product of succession is a sere -- the characteristic sequence of communities that replace each other in a particular environment. Each of the communities making up the sere are known as seral stages (Kimmins 1989).

Primary succession occurs on newly-exposed environments (such as sterile soil exposed after a land slide). Secondary succession occurs on previously colonized environments after a disturbance. (Kormondy 1976; Spurr and Barnes 1976; Kimmins 1989).

The rate at which succession progresses depends upon the moisture and nutrients available in the ecosystem, and succession can be classified by those factors (Spurr and Barnes 1976; Kimmins 1989):

- Moisture - Xerarch, Mesarch or Hydrarch Succession
- Nutrients - Oligotrophic, Mesotrophic or Eutrophic Succession.

The impetus of change is also described: autogenic changes are those which the present community causes such as deepening shade; allogenic changes are caused by geological forces such as flooding, siltation, or erosion; biogenic changes are caused by a component of the ecosystem such as insects or diseases (Kimmins 1989).

Rates of change vary widely amongst seres, and between seral stages. Generally change does not continue indefinitely, but arrives at a condition where change occurs only very slowly. This is termed the climatic climax (Kimmins 1989). One school of thought (the Monoclimax Theory) states that all seres within a given climate terminate in the same climax, because dry ecosystems get wetter, wet ecosystems get drier, and nutritional conditions also moderate. All initial conditions converge on the climax condition over very long time periods.

Kimmins (1989) describes a variety of situations where a sere does not proceed to the climatic climax, but stops instead at an intermediate but very stable seral stage. This may be a subclimax condition maintained by minor disturbances (such as a fire climax in a dry forest) or an early seral stage maintained by grazing pressure.

In general, a climax is a self-replacing community which is relatively stable (persistent). It can generally be identified by an "inverse-J" size or age distribution, as show in Figure 2 below.

Autogenic (caused by the existing community) processes facilitate change by three mechanisms: colonization, alteration of site, and displacement (Kimmins 1989).

Kimmins (1989) describes the processes as follows:

- **Colonization:** the product of invasion and survival. Pioneer species produce large numbers of propagules which are effectively dispersed. Many pioneers have nitrogen-fixing symbionts which help their survival in difficult conditions. Colonization may occur in discrete waves, as each seral stage facilitates its own displacement, and this is known as "relay floristics". Colonization may also occur in a single wave of differently adapted species, each of which dominate the site in turn. This second system is termed "initial floristic composition".
- **Alteration of site:** by occupying a site a species changes the conditions of the site. Those changes may be adverse to the continued occupancy by the species, or favorable to a potential invader. In any case, when the site conditions have changed such that the invaders have better competitive ability than the occupiers, a species shift will occur. The nature of the alteration may be microclimatic (shade, moisture), nutritional (improved nutrient availability) or improved soil conditions (porosity, pH, water holding capacity, bulk density, organic matter content).
- **Displacement:** Occupiers or invaders can displace other species by competitive ability, by allelopathy, or by autotoxicity.

The rate of successional change depends upon the productivity of the ecosystem, the longevity of the species involved and the degree of change required to facilitate the next seral stage (Kimmins 1989). Early seral stages have higher levels of net primary production than later stages, and therefore accumulate biomass more quickly. As gross primary production comes to equal respiration (NPP=0) the ecosystem is no longer accumulating biomass. Spurr and Barnes (1976) state that this state of equilibrium is the climax condition. Kimmins (1989) cites studies, however, which show that in some climax conditions biomass continues to accumulate (i.e. NPP>0).

Succession And Fire

Ecosystems dominated by fire do not follow typical successional progress towards a climax condition (Heinselman 1981a). According to Heinselman (1981a) half of the forest area in North America is a “fire dependent” conifer forest where fires play an integral role in the natural ecosystem by:

- releasing nutrients tied up in accumulated biomass;
- warming cold soils;
- reducing organic forest floor depth;
- creating seed beds; and
- influencing the species composition of the new stand.

Heinselman (1981a) states that fires in conifer forests generally result in replacement by another forest. However, Parminter (1978) showed that fires on the forest-grassland ecotone maintained the grassland ecosystem.

Kimmins (1989) refers to fire as an example of “successional retrogression” whereby an ecosystem is set back to an earlier seral stage. It is clear, however, that low intensity fires may not cause retrogression, but merely maintains a subclimax condition permanently or for very long periods (Kimmins 1989). Heinselman (1981a) describes this situation in dry boreal forests, and in Douglas-fir and lodgepole pine forests of the Rocky Mountains.

Fires apparently result in an initial floristics composition pathway of colonization for trees, shrubs and herbs, but a relay floristics pathway for cryptograms (Heinselman 1981a). Succession in the cryptogram community carries on at a different pace from the herb-shrub-tree community, and the result can be the formation of thick forest floors which sequester much of the available nutrients, cause the soil to cool, and the water table to rise. Both Kimmins (1989) and Heinselman (1981a) refer to studies which describe the formation of upland bogs in the absence of disturbance by fire, and refer to these ecosystems as “depauperate”.

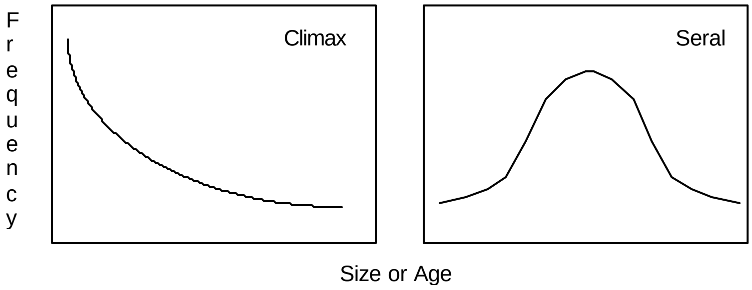

Figure 2: Frequency distribution by size or age as described by seral stage. (After Kimmins 1989).

Natural Disturbance Regimes Of IDF

Fire Regimes

Douglas-Fir grows in a wide variety of ecosystems and associates with a wide range of species in various seral roles (Hermann and Lavender 1990) These ecosystems have a wide range of natural fire regimes (Arno 1980). Various reports describe average fire return periods (number of years between events) which range between 5 and 140 years (Parminter 1978; Arno 1980; Steele et al. 1986; Daniels et al. 1995). Fire return interval and fire severity combine to form the fire regime, which is a product of climate, topography, vegetation, fuel structure, and ignition sources (Kilgore 1981).

Frequent burning at low intensity causes development of uneven-aged stands comprised of even-aged groups of trees in various age classes (Weaver 1967, referenced by Kilgore 1981). Decreases in fire frequency results in diameter distributions skewed towards smaller trees, higher total densities, stagnation and more saplings under mature trees (Kilgore 1981).

As fire frequency declines, fire return intervals increase and burning is postponed (Heinselman 1981b). The resulting changes in stand structure described above change the structure of fuel in the stand, and prepare the stand for stand-replacing fires because of fuel accumulation (living and dead) and laddered fuels which allow fire access into tree crowns (Arno 1980; Kilgore 1981; Steele et al. 1986).

Fire regime selects for species and successional pathways adapted to the regime (Heinselman 1981b). It follows, therefore, that a change in fire regime will cause a change in species composition, stand structure, and successional pathways.

Fire Regimes In The IDF

The morphology of Interior Douglas-fir forests imply a complex historical interaction with fire. Pre-settlement fire regimes range from frequent surface fires to infrequent stand replacing fires depending on ecosystem (Arno 1991). Arno (1991) states that changes in fire frequency as a result of fire management have enabled Douglas-fir to expand its range into grasslands, and to dominate dry ponderosa pine (*Pinus ponderosa* Laws) types which are naturally kept open by fire.

Many authors show fire return periods prevailing in uneven-aged Douglas-fir stands which range between 8 and 50 years in frequency (Parminter 1978; Arno 1980; Kilgore 1981; Daniels et al. 1995). These fires ranged in severity between fire events, and within stands (Steele et al. 1980). Drought and high winds would act to cause intense burning conditions, whereas low fuel conditions would act to reduce fire intensity (Steele et al. 1986). The resulting variable burning conditions yield a patchwork of stand conditions on the landscape, in which some areas are burned intensely, while other areas are completely missed (Arno 1980; Province of BC 1995c).

The Interior Douglas-fir biogeoclimatic zone was naturally maintained as a fire climax, so that forests were open uneven-aged stands interspersed with gaps of grass and shrub lands (Province of BC 1995c). Surface fire frequency ranged between 4 and 50 years, and crown fires occurred at 150 to 250 year intervals (Province of BC 1995c).

Researchers are in unanimous agreement that fire interval has increased since approximately 1900. This change coincides with settlement history in most studies, and Steele et al. (1986) blame it on:

1. cessation of aboriginal use of fire as First Nations communities were moved to reserves and reservations and use of fire was stopped by European settlers intent on protecting buildings, livestock and timber;
2. organized wildfire suppression began; and
3. unregulated grazing by livestock which reduced fuel loads.

Arno (1980) suggests that some fire frequencies may have been maintained at a short interval because of aboriginal use of fire. First Nations people used fire to enhance production of food and medicinal plants, and to enhance forage production for hunted game such as deer and elk.[2]

In a study on the Alex Fraser Research Forest, Daniels et al. (1995) found that two stands in the IDFdk3 demonstrate a pre-settlement fire interval of 16.6 to 18.0 years which ceased in 1915. Parminter (1978) found, in his study nearby at Riske Creek, a fire interval of 9.8 years which ceased in 1926 in the IDF biogeoclimatic zone[3].

There is little doubt that cessation of natural fires has led to increased densities of saplings. Parminter (1978), Kilgore (1981), and Arno (1991) all conclude that cessation of frequent fire in uneven-aged forests has resulted in an increase in the proportion of smaller stems. Arno (1991) points out that occasional severe stand-replacing fires have occurred.

The Province of BC (1995c) has said that:

> “Ecosystems developing under fire suppression are generally atypical and not adequate substitutes for ... fire maintained stands.”

Forest Health

A healthy forest is one which is sufficiently free of insect or pathogen damage to meet management objectives (Byler and Zimmer-Gorve 1991). Forest health is maintained by regulating composition and density (Furniss and Carolin 1980), and maintaining tree vigour (Boyce 1961; Anderson and Rice 1993). Practices which emulate natural stand conditions provide the best resistance to native diseases (Boyce 1961), and maintain ecological processes (Province of BC 1995c).

Stocking

Stocking is a measure of the occupancy of available growing space, and is a function of the number of trees and their size relative to the ideal stand (Davis and Johnson 1987).

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[2] Shirley Mah, Masters candidate, UBC Faculty of Forestry, Centre for Conservation Biology.Personal Communications. 1996.

[3] Parminter classified the area as the Cariboo Aspen Lodgepole Pine zone after Krajina. This area has now been included in the IDF (Hope et al. 1991).

Interior Douglas-fir is able to regenerate in very dense clumps (Parminter 1978; Kilgore 1981) and high-density stands of Douglas-fir suffer more severe and more extended periods of water stress than low-density stands (Furniss and Carolin 1980; Carlson et al. 1985; Korol 1985). Korol (1985) found that high stand density and high crown closure resulted in low growth rates, and concluded that reduced growth is a result of inter-tree competition for limited soil moisture. High stocking levels were felt to be a more significant challenge for management than achieving regeneration in the IDFxw subzone (Day 1996).

A clear relationship exists between tree vigour and attacks by mountain pine bark beetles (*Dendroctonus ponderosae* Hopk.) in ponderosa pine (*Pinus ponderosa* Laws) (Larsson et al. 1983). In discussing bark beetles, Furniss and Carolin (1980) cite Keen (1936) who found that bark beetles attack the oldest, slowest growing codominants and intermediates in a ponderosa pine stand -- the trees one would expect to be least vigourous.

Referencing methods developed by Waring and Pitman (1980), Larsson et al. (1983) showed that density and basal area stocking were determinants of tree vigour. Average tree vigour decreased with denser spacing and with larger leaf area indices. Attacks by bark beetles decreased as average tree vigour increased, and below a tree-vigour threshold significantly more attacks were recorded.

Larsson et al. (1983) also found that vigour varied from tree to tree within treatments. The variation was highest (60%) in unthinned controls, which suggests that some trees in dense conditions are able to maintain their vigour at the expense of other individuals. Variability in vigour within thinned plots was significantly lower (20%), and average vigour was increased after thinning.

Results of Larsson et al. (1983) compare favorably with other authors they cite[4], working in lodgepole pine and ponderosa pine. They recommend maintaining stocking below a critical threshold to avoid mortality caused by bark beetles in endemic population cycles.

It seems reasonable that, if stocking is not controlled by thinning or by fire, low-vigour individuals will continue to be suppressed by more vigourous neighbours. The wide range of vigours found by Larsson et al. (1983) in unthinned stands is probably the normal condition in all natural stands, regardless of species.

Several authors suggest that subordinate canopy layers play a significant role in the vigour of superior layers. Sterba et al. (1993) found that removal of a dense coppice from around oak standards improved the increment of the standards even though the standards were growing completely free of crown competition. Dolph et al. (1995) report results of a 50 year study in northeastern California. They found that, in the absence of fire and thinning, understory densities progressively increased, while overstory trees died out of the stand. They suggest that extreme competition for moisture and nutrients with dense understories has reduced the vigour of overstory trees and rendered them susceptible to bark beetles.

A relationship between vigour, density and damage of Douglas-fir has also been demonstrated for western spruce budworm (*Christoneura occidentalis* Freeman). As

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[4] Waring, R.H. and G.B. Pitman. 1980. A simple model of host resistance to bark beetles. Oregon State University For. Res. Lab and Res. Note 65, 2p.

tree vigour declines, ability to recover foliage biomass suffers; trees of low vigour also have smaller crowns and therefore suffer greater proportional defoliation (Wulf and Cates 1985). In addition, stress modifies foliage qualities to favour budworm development by enhancing survivorship and growth of budworms (Cates et al. 1991). Budworm defoliation is also intensified by multi-layered stand structures such as develop in the absence of fire or thinning (Carlson et al. 1985; Wulf and Cates 1985; Byler and Zimmer-Gorve 1991).

Tree vigour also has implications in disease/tree interactions. Entry et al. (1991) found that thinning may produce Douglas-fir trees which are more resistant to infection by *Armillaria ostoyae* ((Romagn.) Herink), but caution that the benefit of individual tree resistance is easily overcome if significant inoculum remains on site in the form of roots and stumps. McDonald (1991) shows that site quality (described by site index) is an important factor in Armillaria expression. High- and low-quality sites only rarely have significant Armillaria problems, whereas moderate-quality sites have common problems. McDonald (1991) also suggests that stress or vigour profiles are important host attributes for Armillaria expression.

Stand Structure

Stand structure has implications for forest health, as reported by many authors. Wulf and Cates (1985) report that spruce budworm damage is sensitive to stand structure since the dispersing larvae must land on host material to continue maturation feeding. Well-developed vertical structure provides more host in subordinate positions for dispersing larvae. Carlson et al. (1985) indicate that uneven-aged management of Douglas-fir stands is inadvisable in consideration of budworm, because the multi-layered stands are most susceptible to damage, particularly if stocking is not controlled to maintain high vigour.

Multi-layered stand structures also present problems for dwarf mistletoe, since the parasite remains present in superior layers, and promptly infects subordinate layers as they emerge.

Selection Management

Stand Structure Regulation

While regeneration is a critical factor in uneven-aged management (Davis and Johnson, 1986), regeneration success alone is not a good reflection of success of stand prescriptions. It is quite possible to develop good regeneration and growth of small stems by highgrading a stand. Regulation of stand structure and control of stocking is critical to ensuring that stand growth is maintained, and management objectives are met (Hann and Bare 1979).

Uneven-aged management requires regulation of stand structure in order to ensure:

- regeneration;
- growth; and
- salvage of mortality.

Regulation of stand structure is an exercise of setting and achieving objectives. Setting stand structure objectives is a process of design (Daniel et al. 1979; Fiedler 1995). Design factors include the diameter distribution, the maximum diameter of managed trees, the minimum stocking to be retained, and the cutting cycle (Matthews 1991; Guldin 1991; Fiedler 1995). This is frequently termed BDq regulation: residual **B**asal area, maximum **D**iameter; diminution **q**uotient (Guldin 1991; Fiedler 1995).

Regulation of stand structure must be explicit to control over-cutting and ensure operable volumes are available in later entries (Guldin 1991). Regulation also ensures that the desired structure of the stand is maintained for wildlife habitat or other management objectives (Fiedler 1995).

Stand structure is critical to all facets of the uneven-aged system. Changes to stand structure imply changes to growth and yield, allowable cut, harvest practices, inventory, and economics (Leak 1976). Stand structure also dictates regeneration success and species composition (Fiedler 1995).

Selection management requires thinnings amongst all size classes at each entry (Marquis 1976, Matthews 1991, Becker 1995). This ensures that diameter classes are maintained in correct proportions, species composition is suitable, saplings are growing without suppression, and defective trees are removed from the stand.

Early attempts at selection cutting failed due to a lack of regulation, because cutting concentrated on large size classes (Marquis 1976). If little attention is paid to regeneration and maintenance of the stand, the forest is degraded and sustained yield is not provided (Matthews 1991).

Daniel et al. (1979) state that factors to consider in design of stand structure goals include: current vigour in all diameter classes; impact on (or of) windfall, insects, and disease; impacts on wildlife; slash loading; and creation of regeneration opportunities. All of these factors influence the intensity of harvest, distribution of harvest, and return period.

Setting Stand Structure Variables (BDq)

Residual Basal Area (B)

Setting the residual basal area for a prescription is important, because appropriate levels of growing stock ensure that full site potential is captured, and individual tree growth is maximized. Marquis (1976) states that stands cut to 60% of full stocking will exhibit the same stand growth as a fully stocked stand, and maximize individual tree growth. Matthews (1991) states it as “the principle of gaining maximum increment from the smallest possible growing stock”. The level is based upon the relationship of increment to growing stock, as described by Langsaetter (1941, Referenced by Lotan et al. 1988). Figure 3 below shows Langsaetter’s curve.

Simply put, growth is a function of stocking. Too much stocking reduces stand growth, whereas too little stocking results in poor utilization of growing space by trees. There is a fairly wide range of stocking, however, which produces the maximum growth of the stand (Daniel et al. 1979; Lotan et al. 1988). Growing a stand at the lowest stocking which still captures all the growing space (B-level stocking) maximizes both stand growth and individual tree growth (Daniel et al. 1979; SIWG 1992).

In Europe B-level stocking is set based upon periodic inventory before harvesting (Matthews 1991). Marquis (1976) suggests a residual stocking of 80 ft^2/ac for trees 10 inches dbh and greater (18.4 m^2/ha 25.4 cm dbh and greater). Guidelines for the IDF in British Columbia recommend residual stocking of 50 to 75% of the stand volume and 15 to 25 m^2/ha of basal area (SIWG 1992). Ginrich [sic] (1965) suggests that B-level stocking is equivalent to 57 to 59% of full stocking.

Since carrying capacity is a function of site quality, B-level stocking must vary from place to place. Research is necessary to determine appropriate levels of residual stocking by biogeoclimatic subzone.

Diameter (D)

- Maximum D

Setting the maximum diameter class is dependent on site quality and stand management objectives. (Marquis 1976; SIWG 1992; Fiedler 1995). Larger diameters imply greater maximum tree age, and maximum diameter must be consistent with biological capability (Fiedler 1995). Better site quality suggests greater maximum diameter (Fiedler 1995).

Fiedler (1995) recommends that maximum diameter should be set at the size where growth slows, or at a diameter beyond which few trees grow. He further recommends that maximum diameter should not be increased beyond this size on account of non-timber objectives. Rather, he suggests that a basal area reserve be instituted for trees greater

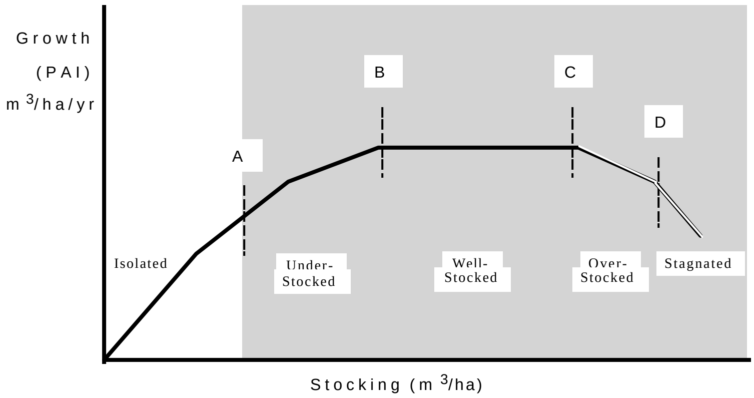

Figure 3: Langsaetter's curve, adapted from Lotan et al. (1988).

than the maximum diameter.

Guldin (1991) suggests that maximum diameter depends upon operability and risk. Large maximum diameters provide large logs, but present increased risk of loss. Smaller maximum diameter may provide slightly higher volume growth, but lower value. While risk of loss of the largest trees is reduced by managing to a smaller maximum, logging damage to the residual stand is increased.

- Minimum D

A minimum diameter for regulation should also be explicitly stated (SIWG 1992; Fiedler 1995). The lower limit may be based upon merchantability, or on the need for management of stand density below merchantability limits.

A limit of 12.5 cm is suggested by SIWG (1992), but since the publication of their report the Chief Forester has imposed a maximum density of 2,000 stems/ha between breast height and 7.5 cm dbh. This suggests that all diameter classes should be considered in setting stand structure goals. Marquis (1976) cautions that, since management depends heavily on the stocking of small classes, it behooves a manager to know what is happening in those classes.

- Diameter Class Width

Diameter class width should be specified. Changing class width has a direct impact on the number of trees to be kept, because it changes the number of diameter classes (and therefore the q-factor) (Guldin 1991). Diameter classes of 5 cm or 2 in. are most often referenced in the literature (Guldin 1991; SIWG 1992; Fiedler 1995) but larger diameter classes may be used and are preferred by some authors (Becker 1995; Fiedler 1995).

Diminution Quotient (q)

The q-factor is a constant ratio of the number of trees in successively smaller diameter classes (Fiedler 1995).The concept of q-factors was first developed by de Liocourt in the late 1800's, and when drawn on logarithmic scales, is referred to as de Liocourt's constant (Matthews 1991). High q-factors provide for more small trees, whereas low q-factors provide for more large trees. Low q-factors concentrate basal area in larger diameter classes (Daniel et al. 1979; Fiedler 1995), and therefore favour the production of large sawlogs (Guldin 1991).

Selection of an appropriate q-factor is a function of stand management objectives (Daniel et al. 1979). Open forests which naturally developed under a fire-maintained subclimax would have had a relatively low q-factor (Fiedler 1995). A wide range of q-factors are suggested in the literature. For 2 inch or 5 cm classes, suggested q-factors range from 1.1 to 2.0 (Marquis 1976; SIWG 1992; Fiedler 1995).

Lower q-factors tend to produce better volume growth because more of the increment is being concentrated on larger stems (Marquis 1976; Leak 1988). Initial harvest in an unregulated stand should employ a q-factor slightly higher than the eventual target q-factor (Marquis 1976; Daniel et al. 1979; SIWG 1992; Fiedler 1995). To approach a low q-factor on the first cut will result in a very open understocked stand (Leak 1976; Daniel et al. 1979).

Cutting Cycle

The cutting cycle is the cornerstone of the management prescription in uneven-aged management (Davis and Johnson 1987). The cutting cycle should be set so that periodic diameter growth averages one diameter class (Fiedler 1995). Schutz (1975) shows, however, that in forests managed for many decades under uneven-aged methods, the rate of diameter growth increases with increasing diameter.

Based upon the assumption that forest management should approximate natural disturbance (Province of BC 1995c) it follows that cutting cycle should be set at an interval which approximates the dominant stand-maintaining disturbance.

According to Marquis (1976) cutting cycle depends upon growth rate, residual stocking after cutting, and site quality. The cycle should be long enough to allow the stand to return to 80 or 90% of full stocking. Cutting cycles of 15-25 years are appropriate for many types (Marquis 1976), but European cycles are generally less than 10 years (Matthews 1991).

In practice, the forest is divided into roughly equal compartments, equal in number to the length of the cutting cycle. One compartment is then cut in each year (Matthews 1991). Short cutting cycles give large felling areas for small volume (Matthews 1991), but assure the salvage of all mortality and more constant control over stocking. Long felling cycles reduce the area of each compartment, and thereby improve the economic efficiency of the harvest (Matthews 1991). Longer cycles increase the risk of loss through mortality and reduce the stocking control exerted. Matthews (1991) also states that long cycles with small compartments favour more light-demanding species, because of relatively more intensive cutting.

Marking

Once stand structure (BDq) goals have been stated and the cutting cycle has been determined, the prescription is ready for implementation in the stand. According to Anderson and Rice (1993), “Tree marking is the mechanism that facilitates the regulation of those management systems that involve partial cutting...”. Marking applies the stand structure objectives to the stand as it exists at the present time.

In British Columbia marking may be done by experienced markers who designate trees to be cut or retained, or by faller selection (SIWG 1992). However, very few other jurisdictions use faller selection.

Trees marked for retention should be (SIWG 1992; Matthews 1991):

- of good vigour (able to survive through the following cutting cycle);
- of favoured species;
- of good form;
- capable of producing seed;
- exerting desired influence on microclimate.

Marking is a critical step in implementation of an uneven-aged prescription, and it is important that it be done considering the residual stand rather than the harvested timber.

The residual stand must not be simply comprised of “left-overs” (Fiedler 1995). Marking is particularly important in the first entry into stands because of the large number of stems and wide range of quality and vigour in the unmanaged stand (Fiedler 1995).

Marking guides are generally written to interpret stand-level objectives for stocking, structure, density and arrangement into tree by tree decisions. The guides provide quantitative instruction to markers with respect to how many trees to cut in a given size class (Marquis 1976, Guldin 1991). Marking guides also provide tree classifications for qualitative decisions (Anderson and Rice 1993).

Qualitative decisions can be based upon either tree grading or tree classification. Tree grading is focused on the qualities of the logs to be cut, and tree classification is focused on the qualities of trees to be retained (Anderson and Rice 1993).

Marking guides are formulated (Anderson and Rice 1993) to consider:

- the silvics of the species;
- the ecology of the site;
- the character of the stand.

Theoretical marking decisions can be made based upon present net worth and soil expectation values for individual trees (Davis and Johnson 1987). It is plain, however, that marking decisions come down to a simple rule: “Cut the worst and leave the best.” (Guldin 1991). Matthews (1991) points out that vigourous, well-formed trees of any size may be left to put on increment, and appropriate marking removes trees in the following order of cutting:

1. dead and dying trees;
2. diseased or defective, or of low vigour or undesirable species;
3. healthy merchantable trees.

Good marking therefore foresees mortality and removes trees which will die, thereby harvesting all mortality.

Because all trees are cut before or shortly after they die, there is great potential for a negative impact on biodiversity. Prescriptions must include an allowance for recruitment of wildlife trees, which will die and eventually fall over (Anderson and Rice 1993; Fiedler 1995). Fiedler (1995) suggests that this is best accomplished by setting a basal area reserve which exceeds the maximum diameter set in the stand structure goals. This would allow some trees to grow beyond the maximum diameter and never be marked for cutting.

In British Columbia, tree marking is considered to be valuable initially, until fallers are trained and experienced in tree selection. At that point faller selection might be employed (SIWG 1992). Fiedler (1995), however, calls for a strong emphasis on characteristics of trees to be left rather than an emphasis on trees to cut. This position is supported by Anderson and Rice (1993). Few jurisdictions allow faller selection and instead require timber to be marked by marking crews.

Tree classification systems are described by Anderson and Rice (1993) for the tolerant hardwoods working group of Ontario. Such systems may have two classes (Acceptable or Unacceptable Growing Stock) or up to six classes. The classes are based upon quality and risk of loss. Systems with more classes better define the quality and risk associated with a given tree, but are more difficult for markers to implement. The six-class system proposed by Anderson and Rice (1993) and in use in Ontario is shown below in Table 1.

Table 1: Classification system with 6 classes. (After Anderson and Rice (1993)).

Class	**Description**
A1	A great tree with a good future
A	A great tree with a poor future
B1	A fair tree with a good future
B	A fair tree with a poor future
C	A poor tree
D	A cull tree

In dry ecosystems such as the IDF Biogeoclimatic zone, trees tend to survive at very high densities, in a state of stagnation. Trees do not die as a result of drought or moisture competition. Instead, they shed leaves to reduce their transpiration demands. As trees shed crown volume, ambient light levels are maintained and mortality is averted.[5] In dry forests, therefore, tree vigour is a better method of classification than anticipated mortality. The Collins Pine Company of Chester California has devised a nine-step classification system which focuses on crown form as an expression of tree vigour (Mason and Howell n.d.). That classification system is shown below at Figure 4.

Fitzgerald (n.d.) advocates timber marking based upon the functionality of each tree in achieving management objectives for a stand. Based upon explicit criteria, trees can be declared either functional or dysfunctional. Trees are only cut if they are determined to be dysfunctional or excess. Fitzgerald (n.d.) claims that this approach to marking provides a conceptual framework which ensures that all objectives are satisfied in the marking process.

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[5] Hamish Kimmins. Personal Communications, Aug. 1996.

Schmidt et al. (1976) provide qualitative criteria for identifying vigourous trees based upon crown and bark characteristics. Table 2 describes those criteria for interior Douglas-fir.

Regeneration

According to Leak (1976), the fundamental theory which underlies selection management states that: if a population is subject to consistent mortality and fertility rates, the population will settle to a stable age distribution. In selection management, mortality is supplied by cutting, and fertility must be ensured by providing required stand structure, seed bed, and seed supply.

Periodic regeneration (subsequent to harvesting) is a requirement of selection management (Daniel et al. 1979; Matthews 1991; Becker 1995), because regeneration feeds the lower end of the diameter distribution (Leak, 1976). It is a critical assumption in selection management that regeneration is on-stream; failure to assure regeneration threatens the sustainability of the prescription (Marquis 1976; Davis and Johnson 1987).

Table 2: Vigour classification by qualitative descriptions for interior Douglas-fir (after Schmidt et al. 1976).

Characteristic	Good Vigour	Fair Vigour	Poor Vigour
Crown Class	Dominant or Codominant.	Codominant or Intermediate.	Intermediate or Suppressed.
Live Crown Ratio	> 40%	20 - 40%	< 20%
Crown Shape	Pointed to rounded.	Rounded to flat.	Flat or spike-topped.

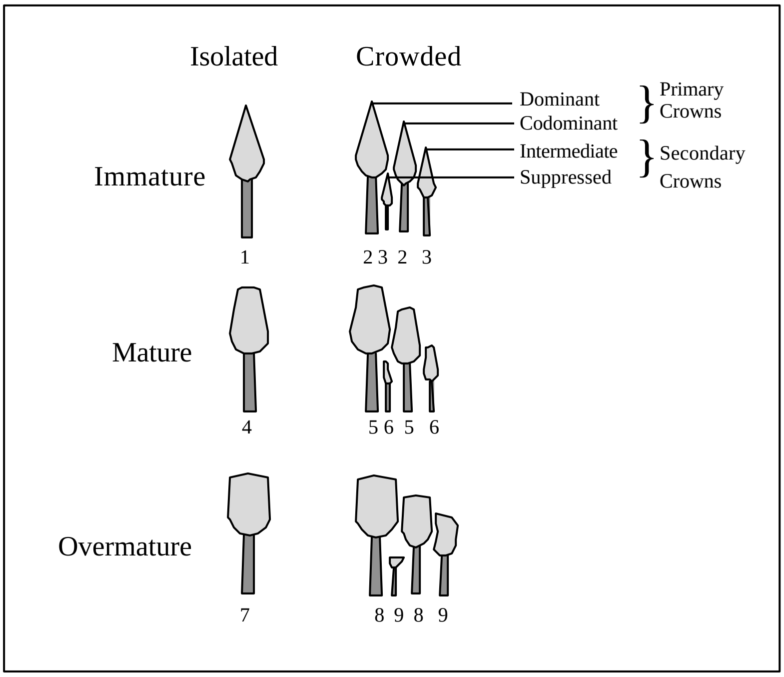

Figure 4: Collins Pine Almanor Tree Classification, from Mason and Howell (n.d.).

Crown and Foliage	Dead branches rare. Foliage moderately dense or better.	Occasional dead branches. Foliage moderately dense.	Dead branches frequent. Foliage thinning to sparse.
Bark	Dark bark plates at base are broad with well exposed new bark between. Upper bole – ¼ or more of tree height light gray and smooth.	Less exposed new bark between plates. Upper bole – less than ¼ of tree height light gray and smooth.	No new bark exposed between plates. Upper bole – dark gray rough bark for entire stem.
Insects or Disease	Free of damage.	Light damage.	Mod. to heavy damage.

Stocking Control

Many authors cite stocking control as a principle requirement of selection management (Marquis 1976; Long 1988; Lotan et al. 1988; Becker 1995). Matthews (1991) emphasizes that selection management requires thinning in all size classes to ensure that:

- numbers of stems are maintained in the correct proportions by diameter class;
- species composition is controlled;
- saplings are maintained free of suppression; and
- defective stems are removed from each size class.

Marquis (1976) discusses the pitfalls of not thinning in sub-merchantable size classes:

- unregulated stocking in small size classes may contribute a significant amount of the stand basal area;
- distribution of basal area is skewed towards smaller diameter classes, despite the design objective set by the chosen q-factor;
- there is always very heavy cutting in the first merchantable size class, which may reduce the profitability of the harvest [and the stability of that component of the stand].

The stocking standards prepared by the province for uneven-aged management of interior Douglas-fir in British Columbia (Province of BC 1995b) indicate that a stand may be stocked by retaining an appropriate minimum number of trees in one layer or a combination of layers. A maximum number is stated for the smallest diameter class. Each layer may satisfy the standards alone, or contribute to the density of the whole stand. As shown in Table 3 following, this approach is focused on regeneration, and does not consider the stocking of the stand in the sense of site occupancy. Maintenance of B-level stocking is a much more meaningful goal than meeting the minimum or target densities set out in Table 3.

Table 3: Free-growing stocking standards for single tree selection, and resulting basal area stocking (Adapted from Province of BC 1995b).

Layer	Lower DBH	Upper DBH[6]	Min. Trees/ha	Target Trees/ha	Max. Trees/ha	Min. BA (m^2/ha)	Target BA
1	12.5	60	300	600	--	3.68	?
2	7.5	12.4	400	800	--	1.77	9.66
3	0	7.4	600	1000	2000	0.00	4.30
4	Regen	0	700	1200		--	--

In analysing data collected by the Ministry of Forests in the IDFxw, it became apparent to me that there are problems in stocking control which relate to overcutting in large size classes, and undercutting in small size classes (Day 1996). This problem in stocking control results in part from a lack of tools to assist in setting stocking targets, and from a lack of control in marking.

One tool which could assist in setting stocking targets is the Gingrich Stocking Chart (Marquis 1976). Gingrich curves represent the mathematical relationship between density, basal area, and quadratic mean diameter (Lotan et al. 1988). In addition, the maximum size/density relationship is plotted on the chart, typically using Reineke's stand density index and concepts of stocking described by Langsaetter (1941; cited by Lotan et al. 1988). I created a Gingrich Stocking Chart for the IDF zone, shown at Figure 5, which may have some application but requires extensive testing (Day 1996). The chart shown at Figure 5 shows a maximum size/density relationship taken from stand density management diagrams drawn by Farnden (1996). The B-level stocking and the Zone of Imminent Competition Mortality (ZICM) are calculated according to Drew and Flewelling (1979). They report that B-level stocking is equal to a relative density of 0.4, and the ZICM is equal to a relative density of 0.55. It is important to note that Drew and Flewelling (1979) did their work with even-aged coastal Douglas-fir. It is critical that B-level stocking be established for uneven-aged interior Douglas-fir before this chart is employed. Note that Ginrich [sic] (1967) found that B-level stocking was at 55 to 58% of full stocking in even-aged upland hardwoods.

Increment

Determining radial growth, and hence diameter and basal area increment, is a fundamental requirement for estimating productivity and hence appropriate cutting cycle (Gingrich 1976; Daniel et al. 1978; Davis and Johnson 1987). In general, radial growth is measured for all trees on a plot, to determine growth on a "per hectare" basis[7]. I found that periodic increment was highly correlated (75%) with current stocking in the IDFxw (Day, 1996).

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[6] Note that no maximum diameter class is stated in the guidelines. Sixty centimetres is frequently shown in the text as the maximum diameter class. I recognize that IDF sites will not support basal areas of more than about 60 m^2/ha.

[7] Gordon Weetman. Personal communications. 1996.

Schutz (1975) and Gingrich (1976) both conclude that diameter growth is a function of DBH (larger stems grow more quickly in diameter). Schutz (1975) further concludes that diameter growth is influenced by cumulative basal area of trees in larger diameter classes. These conclusions make sense, since larger trees are in a better competitive position and are able to dominate growing space at the expense of smaller trees, assuming appropriate stocking levels. Saraçoglu (1988), however, found that small diameters had the best increment at low densities, while large diameters had the best increment at high densities.

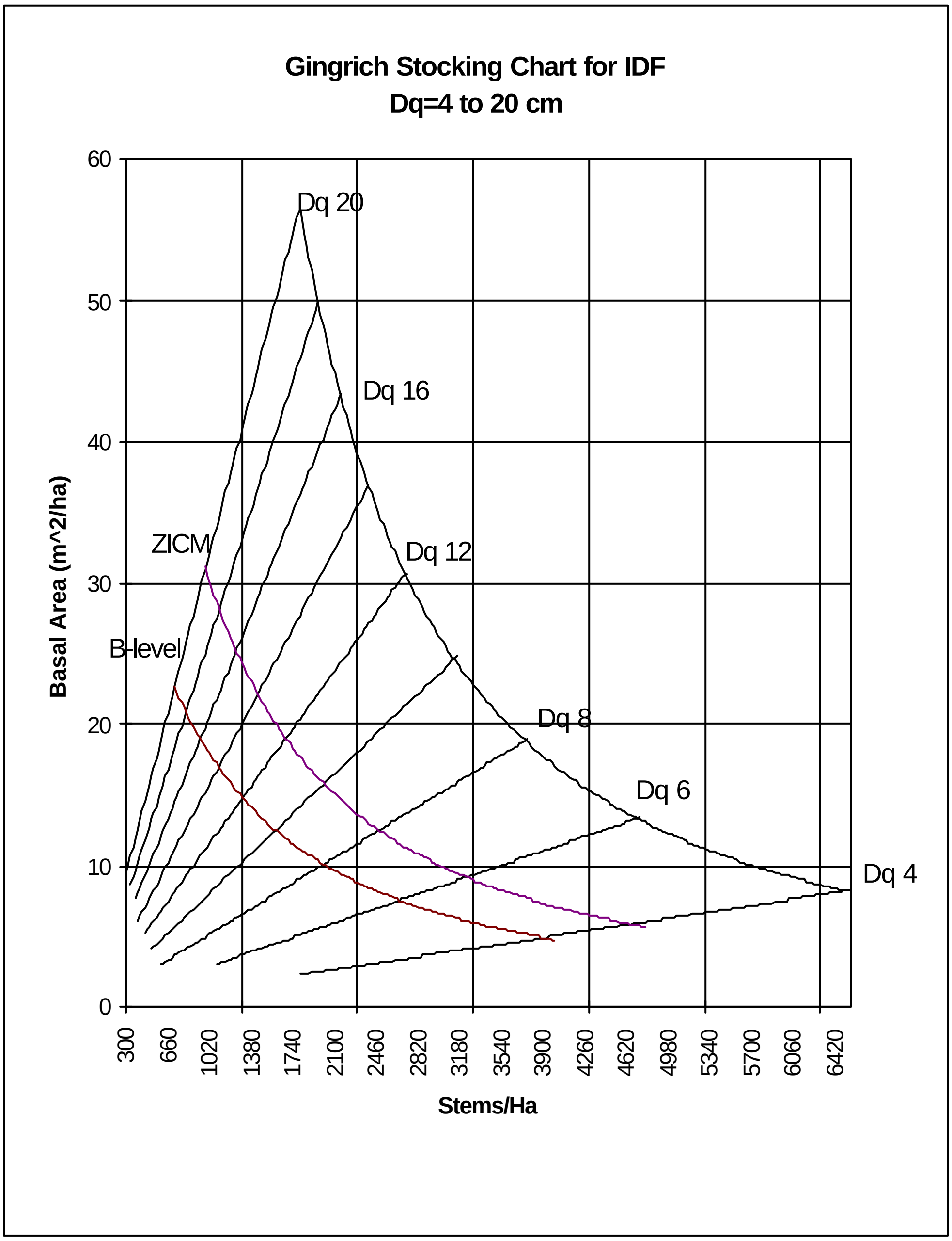

Figure 5: A draft Gingrich Stocking Chart for IDF from Day (1996).

Summary of Literature Review

Throughout much of its range, interior Douglas-fir grows in a climax condition in open uneven-aged stands maintained by frequent low intensity fires. Climax forests display a diminishing distribution of frequency with respect to size (inverse-j shape), which can be approximated by the concept of de Liocourt's constant or a diminution quotient (q-factor).

In the absence of disturbance, leaf area index accumulates. Excessive LAI's result in reduction of growth efficiency for individual trees, and falling net production for the stand. Disturbance is therefore critical to maintaining stand productivity.

Low intensity disturbance at frequent intervals tend to maintain a stand in one successional stage, in a stable condition. Trees which remain after a low intensity disturbance benefit from improved moisture status and fertility, and are less susceptible to herbivory and pathogens. Infrequent disturbances tend to be of higher intensity, and re-initiate secondary succession.

The dominant disturbance in the IDF has been fire, but fire frequency has declined all across western North America at a time coincident with European settlement. Pre-settlement fire frequencies ranged from 4 to 50 years. Cessation of aboriginal use of fire has caused the density of stands to increase, forests to invade grasslands, and incidence of catastrophic fire and insect infestation to increase. High stand densities result in low tree vigour, and low vigour increases susceptibility to insect outbreaks (particularly bark beetles and defoliators).

Selection management is an attractive option for managing Douglas-fir because it addresses the environmental requirements of the species (shelter for regeneration, regulation of stocking) and accurately mimics the natural regimes under which dry-belt Douglas-fir forests have evolved.

IDF forests are principally limited by moisture availability, and interior Douglas-fir is moderately shade tolerant. It is therefore imperative to maintain stands in an open condition which allows sufficient moisture and light to reach all trees. Stand structure goals are a function of stand management objectives and tree silvics (shelter requirements and shade tolerance). Most managers in dry forests in Western North America are managing relatively low q-factors (1.1-1.3 for 5 cm dbh classes), and fairly large maximum diameters. Residual basal areas are relatively high, and should not be less than 60% of full stocking.

Harvesting must be controlled by marking, and markers should be fully competent to implement the stand structure goals to the benefit of the residual stand. Faller selection is not practised in any other jurisdiction except British Columbia. Marking should be done on a mark to leave basis, based upon the health and vigour of residual trees.

Stocking control must be executed in all diameter classes at each harvest entry, so pre-commercial thinning is a requirement of the selection method. The current stocking standards for uneven-aged Douglas-fir published by the Ministry of Forests do not adequately consider the stocking of the stand in the sense of site occupancy. Maintenance of B-level stocking is a more valid stocking standard.

OPERABILITY OF UNEVEN-AGED IDF FOREST

History Of Harvesting In The Cariboo

Commercial harvesting of timber in the IDF commenced in the 1850's and 1860's, to satisfy the local demand for wood for the settlement which accompanied the Cariboo gold rush. This demand must have been very small in relation to the area of the IDF, since the demand was very localized, and of relatively brief duration.

Significant logging did not commence in the IDF of the Cariboo until the PGE railroad was built in the period around 1920. At that time demand for railroad ties spurred some harvesting. However, it wasn't until after the great depression and the advent of the second world war that harvesting began in earnest. Harvesting for ties, timbers, and boards increased demand, and the number of small mobile sawmills working in the bush increased to meet the demand.

Because there was limited mechanization available for logging at the time, much of the skidding was done by horses to central tractor or truck roads, whereby the wood was forwarded to the sawmills. When the economic range of travel was exceeded, the bush mill was moved.

Since the primary skidding method was by horse, harvesting concentrated primarily upon trees which could be efficiently skidded. This physical limitation of the logging technology resulted in residual stands which were very lightly cut, and still had most diameter classes well represented.

In the 1950's and 1960's, with the advent of mechanical skidders, such limitations vanished. In the same period, bush mills were phased out almost overnight with a change in policy which required that mill waste be chipped and used to furnish a new pulp and paper industry. Sawmills were therefore moved to the rail-heads where their chips could be shipped most efficiently to the pulp mills, and log trucking became a significant part of the industry (Vyse et al. 1991). The logging method was termed diameter-limit cutting, whereby authority was granted to cut all the trees over a set diameter. This method was economically very efficient, but disastrous in terms of stand structure, stocking control, and regeneration.

Throughout the 1970's change was afoot, as regulators tried to assert some control over the quality of the residual stand. They first took the approach of increasing the diameter limit employed, so that more stems would be left after logging. Eventually, however, a significant change towards selection management was made in 1980, with the adoption of the Faller Selection method developed in Kamloops. Based (somewhat loosely) on the classical selection method, Faller Selection directed the faller to cut in all merchantable size classes, and provided guidance as to desirable leave tree characteristics.

The Forest Act was re-written in 1978, and this legislation further entrenched volume-based tenures in the industry. Tenure is granted for a volume of Allowable Annual Cut (AAC) within a very broad geographic area which is shared amongst several licensees. Those licensees, who are responsible for planning the harvesting at the stand level, have no guarantee of returning to harvest a given stand on subsequent passes. Planning has, therefore, been short-term in nature.

In 1987 the provincial regulations were changed to require that licensees are responsible for all activities to achieve a free-growing stand of trees on any areas harvested. This has caused licensees to ensure that harvesting leaves a residual stand which, when combined with resultant regeneration, leaves a stand stocked to the standards shown in Table 3 (page 22). Stands may be declared free-growing five years after harvest (Province of BC 1995b) if sufficient acceptable trees remain after harvest to meet stocking requirements.

In 1992 new guidelines were introduced for management of uneven-aged dry-belt Douglas-fir (SIWG 1992) which took a further step towards the classical selection method. According to those guidelines, managers were required to design stand structure and stocking goals by BDq regulation, and further guidance was given for cut and leave decisions. Fallers were still left with the prerogative of designating which trees should be cut.

In 1995 the Forest Practices Code Act of B.C. was enacted. This mass of legislation, regulation and guidance has had a profound effect on the practice of forestry in B.C. Licensees and individuals are strongly focussed on “due diligence”. This frame of mind has caused some licensees to move towards marking all stands to be harvested by uneven-aged management, rather than leave the marking to “fallers selection” Further, increased regulation and guidance for Silviculture Prescriptions has focussed new attention on description of residual stand structure and stand structure regulation.

Operating Costs And Timber Value

Logging in the dry-belt is inexpensive because of the combination of easy logging on relatively flat ground, and proximity to highways and sawmills. The Douglas-fir timber produced is quite valuable because it is slow-grown and of large diameter. These factors make logging in the dry-belt Douglas-fir quite profitable, both for companies and the public owners of the timber.

I estimate the cost of partial-cut logging (excluding road construction and maintenance) and trucking from the Knife Creek Block of the UBC/Alex Fraser Research Forest to range between \$23 and \$28/m^3. The marginal value of the timber to the local sawmill ranges between \$85 and \$110/m^3 [8]. It appears there is considerable room between costs and value of dry-belt Douglas-fir to allow increased expenses for activities such as marking, lower volume removals, and more frequent harvest passes.

Highgrading And Conversion

Frequent entries to selectively log the biggest stems from a stand are the result of unregulated harvesting. Such selective cutting is dysgenic (i.e. results in deterioration of the genetic resource) (Howe 1995), because superior genotypes are most likely to be harvested, and inferior genotypes will comprise most of the residual stand. Leaving poor

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[8] Based upon timber sales prices over the past three years. Prices have ranged between \$40/m^3 and \$110/m^3 over a nine year period.

quality trees is more effective at achieving genetic loss than leaving good quality trees is at achieving genetic gain (Howe 1995). In eastern Canada, most of the tolerant hardwoods forests have been selectively cut repeatedly, until the residual stand is primarily composed of culls and pulp wood[9]. In British Columbia, some valleys had been selectively logged three or four times on 10-15 year cycles by the beginning of World War II; some other areas had not been logged at all (Vyse et al. 1991).

Dry-belt Douglas-fir stands have a history of highgrading made possible because of the presence of advanced regeneration. Even when all of the merchantable timber has been removed, the stands still appear to be forested. However, the advanced regeneration is typically overstocked, of low vigour, and poorly distributed with gaps in the canopy. The residual stands are therefore not capable of growing at a rate which maximizes site productivity.

In stands where Douglas-fir is growing with seral species such as larch (*Larix occidentalis* Nutt) and ponderosa pine, selective logging without adequate regulation has caused a conversion in species composition. As the dominant seral species trees are removed, the gaps created are regenerated by more-tolerant Douglas-fir, and the highgrading gradually causes a conversion of the stand to Douglas-fir. This problem is reported by Fiedler (1995) and other authors, who advise that stand structure goals for uneven-aged management provide sufficiently-open conditions to retain or promote the seral species.

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[9] Zoran Majcen, Ing. For. Minstère de L'Énergie et des Ressource (Forêts). Personal communications. 1995

MANAGEMENT INTERPRETATIONS

1. Interior Douglas-fir is highly variable in its genetic makeup, and displays genetic variability on longitudinal, latitudinal and elevational clines. It is also extremely variable within populations, and between populations within a region. One way to preserve that variability is to employ natural regeneration based upon eugenic selection of parents.
2. Interior Douglas-fir inhabits areas with harsh climatic conditions, at the forest/grassland ecotone. In those extreme conditions it requires shelter from the drought, insolation, and growing season frost, as can be provided by partial cutting.
3. High stocking levels reduce stand and tree vigour, and thereby contribute to forest health problems such as bark beetles and defoliators. Stocking levels must be controlled in all canopy layers to promote stand health and adequate growth.
4. The natural history of dry-belt Douglas-fir consists of frequent light disturbance by fires and insects, which caused the forest to develop into open uneven-aged stands These forests were important to wildlife and first-nations peoples.
5. Selection management of interior Douglas-fir provides a method of managing the forest which satisfies all of the natural precedents described above: natural regeneration under the shelter of a residual stand, to create an uneven-aged forest which is frequently disturbed by light harvests. It is plain to me that preservation of dry-belt Douglas-fir stands requires active management, because the natural climax condition is dependent on frequent light disturbances.
6. Stands which have been highgraded in the past may require planting of high quality stock, to improve the genetic constitution of the stand (Howe 1995). This is especially applicable to stands which have been repeatedly cut by diameter limit.
7. Creating stand structure goals should follow the BDq regulation method. Setting the ideal structure is largely a process of design, and is dependent on management goals. Managing a stand for mule deer winter range will probably result in different stand structure goals than managing to maximize timber production. Low q-factors are favoured to produce large trees in an open stand.
8. Biological limitations obviously influence the range of workable stand structure solutions. For example, availability of regeneration may dictate the use of a particular range of q-factors, or pathological limitations may restrict the maximum diameter value.
9. Setting B-level stocking is the most difficult step in designing stand structure goals, because information on stand growth is required. In my opinion we currently have no adequate guidance for making residual stocking decisions in selection management for B.C. In the absence of any specific guidance, the stocking limit should be set conservatively, as a proportion of the current growing stock. Suitably conservative B-level stocking is between 60 and 70% of current growing stock.
10. Residual stocking should be left in a somewhat clumpy fashion, to provide regeneration opportunities for moderately-tolerant Douglas-fir. Larger gaps should be

created to maintain less-tolerant species such as ponderosa pine and larch where they occur.

11. Stand level biodiversity must be explicitly provided for, since selection management harvests all trees before mortality occurs. If standing dead and down trees are important for stand level biodiversity objectives, they must be actively recruited.
12. I do not believe it is advisable to forecast growth and yield for uneven-aged management using the tools we have on hand for even-aged management. In the time it takes us to collect information to be used in uneven-aged programs, we should use even-aged management tools very cautiously.
13. It is very important to realize that ideal stand structures cannot be attained in one pass. Some authors recommend that, when bringing a stand under regulation, higher q-factors be employed to recognize that unregulated stands have much of their basal area in smaller diameter classes. It takes several entries to approach the ideal structure.
14. It is likely that ideal stand structures can never be attained but only approximated.
15. Harvesting should be controlled by marking. Trees should be "marked to leave", so that markers are concentrating on the stand they are reserving, rather than the logs to be cut. Markers are trained in both mensuration and forest operations, and must be able to distinguish tree quality, operability, and quantities by diameter class.
16. Traditionally selection management is controlled by area regulation. This is workable for area-based tenures or private land, but is problematical for volume-based licensees. Volume-based tenure arrangements seem to preclude area control and classical approach to cutting cycles and compartments. Tools (such as history record systems) are in place to enable periodic return for subsequent harvest entries.

FURTHER STUDY REQUIRED

1) Stocking by biogeoclimatic subzone:
   - Full stocking;
   - B-level stocking;
   - Relationship between stocking and mean stand diameter.
2) Develop general marking guidelines.
3) Use of fire in stands under selection management:
   - Appropriate burning conditions;
   - Methods of control;
   - Damage to residual trees;
   - Optimum coordination with harvesting.
4) Environmental implications of prolonged absence of fire.
5) Growth and yield of selection forests:
   - Measures of site quality;
   - Development of yield models;
   - Support for AAC calculations.
6) Relationship between Douglas-fir bark beetle, tree vigour, and stocking.

CONCLUSIONS

Dry-belt Douglas-fir forests cover a relatively small area in the landscape of British Columbia, but they are important to the people of the province because they are close to our communities, support wildlife and domestic grazing, provide recreational opportunities, and provide valuable timber to be processed by industry.

Interior Douglas-fir is a species which can be difficult to manage because of its genetic variability and its occupancy of harsh habitats. Selection management offers opportunities to manage dry-belt Douglas-fir which are not afforded by any other silviculture system. This has long been recognized, but we have been slow to adopt the whole management package. Results have been poor, in many cases, when we have not carried out all the components of the selection method completely.

Our principle failures to date have resulted from highgrading:

- destruction of existing stand structure through diameter-limit cutting;
- dysgenic selection;
- failure to ensure regeneration at each entry; and
- failure to control stocking in all diameter classes, leading to stagnation.

Significant improvement has occurred since adoption of faller selection, and more recently when the dry-belt fir guidelines were drawn up. The Forest Practices Code continues to press us forward. Potential for further improvement exists when improved growth and yield information are available, and when marking is more widely adopted. Better regulation will also occur if area regulation is adopted.

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