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Land Units and Benchmarks for Developing Natural Disturbance-based Forest Management Guidance for Northeastern British Columbia

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Ministry of Forests and Range
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EXECUTIVE SUMMARY

There has been a steady increase in the use of knowledge of natural disturbance dynamics as a basis for forest management policy directed towards maintaining biological diversity. While the merits of this approach are currently being debated, especially in light of climate change, knowledge of natural disturbance patterns provides useful baseline information to assist with landscape level planning and stand level forest practices.

This document outlines an ecological land delineation process that focusses on differences in disturbance rate and pattern and successional dynamics for northeast British Columbia. It provides some general principles regarding natural disturbance-based management and, for each delineated unit, detailed information on location, climate, vegetation, natural disturbance dynamics, forest management effects on natural pattern, and recommended forest practices based on the natural disturbance-based management paradigm.

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1 INTRODUCTION

There has been a steady increase in the use of our knowledge of natural disturbance dynamics as a basis for forest management policy directed towards maintaining biological diversity (Booth et al. 1993; B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995; DeLong 2007). The underlying assumption is that the biota of a forest is adapted to the conditions created by natural disturbances and thus should cope more easily with the ecological changes associated with forest management activities if the pattern and structure created resemble those of natural disturbance (Hunter 1993; Swanson et al. 1993; Bunnell 1995; DeLong and Tanner 1996; Bergeron and Harvey 1997; Angelstam 1998; DeLong and Kessler 2000).

For a variety of reasons, earlier forest management policies and guidelines within British Columbia were directed towards setting somewhat arbitrary limits for allowable patch size or harvest amounts. These limits were often related to meeting timber volume targets, addressing perceived public concerns, or creating conditions that favoured certain organisms (e.g., ungulates). Limits were often stated for things such as block size, species composition, stand density, not sufficiently restocked area, and soil disturbance. Although well meaning and easily administered, these practices resulted in landscape scale patterns bearing little similarity to those created by natural disturbance dynamics. Studies of natural disturbance in the boreal forest have demonstrated large ranges in disturbance patch size (Eberhart and Woodward 1987; DeLong and Tanner 1996), tree density (DeLong and Kessler 2000), and volume of coarse woody debris[1] (CWD) (Clark et al. 1998; DeLong and Kessler 2000). Adopting forest management practices that approximate the "natural range of variability" (NRV) has recently been promoted as an appropriate way to manage for the needs of many organisms. More recently the NRV approach has been questioned but is still felt to provide a useful tool to inform practices rather than to set strict targets (Thompson et al. 2008). The principles of forming irregular boundaries of harvest openings to increase edge, leaving behind structure from the previous stand, and having a range of opening sizes are all examples of lessons learned from natural disturbance that apply to the management of resilient forests in the face of climate change.

The Biodiversity Guidebook (1995) was the first attempt in British Columbia to present guidance for forest management based on the natural disturbance template. Specific guidance for seral stage distribution, patch size, wildlife tree patch amount, and spatial arrangement, and more general guidance on species composition and stand structure were included in this guide. Since the completion of the Biodiversity Guidebook, more information on natural disturbance dynamics has become available. Within the eastern portion of the Northern Interior Forest Region (i.e., former Prince George Forest Region), a number of studies have investigated particular aspects of natural disturbance (e.g., DeLong 1998; DeLong and Kessler 2000; Lewis and Lindgren 2000; Rogeau 2001). This document provides an updated and published reference to this information, most of which was previously

1 All reference to CWD in this document refers to dead woody material on the ground or < 45° angle to the ground if suspended.

contained in an unpublished report.[2] The recommendations of the Biodiversity Guidebook were based on the NRV concept but represent a compromise between biodiversity and timber management objectives. This document presents context for deriving management objectives and targets based only on what is known about natural disturbance regimes in the study area. Thus, the guidance presented, which is based on "the best available information," outlines objectives and practices that would result in the least possible differences between harvesting and natural disturbance. Balancing the implications of this approach with potential impacts on deriving or maintaining important goods and services from the forests is discussed only briefly in the final section.

Instead of adopting the Natural Disturbance Types (NDTs) presented in the Biodiversity Guidebook (1995), this document presents information for 10 Natural Disturbance Units (NDUs) (Figure 1). Based on documented differences in disturbance processes, stand development, and temporal and spatial landscape pattern, these units are thought to better reflect important elements that were not dealt with sufficiently in the NDT mapping.

In the drawing of the boundaries of the NDUs, landscape unit boundaries were used whenever possible. This avoids the problem of having very small areas within a landscape unit with different guidance than the rest of the landscape unit. More discussion of the method of creating the NDUs can be found in DeLong (2007). Note that based on further analysis of disturbance regime, an additional NDU (the Cariboo Mountain Foothills) has been added since DeLong (2007).

Information presented for each NDU includes background information on climate and vegetation, discussion of natural disturbance ecology, discussion of the major effects of forest management on natural patterns, and recommended practices based on the natural range of variability management concept. Table 1 provides a breakdown of biogeoclimatic units found within each of the NDUs. Some NDUs are subdivided into low elevation (e.g., valley, plateau) and upper elevation (i.e., mountain) sub-units due to differences in climate, disturbance history, or succession. These sub-units are not shown on the map, but correspond to existing biogeoclimatic units.

2 C. DeLong. 2002. Natural disturbance units of the Prince George Forest Region: guidance for sustainable forest management. B.C. Min. For., Prince George, B.C. Unpubl. internal report. 38 p.

FIGURE 1 *Natural Disturbance Units of the former Prince George Forest Region.*

TABLE 1 *List of biogeoclimatic units[a] within each Natural Disturbance (Sub-)Unit*

Natural Disturbance (Sub-)Unit	Biogeoclimatic units [b]
Boreal Foothills–Mountain	ESSFmv2, (ESSFwk2, ESSFwc3)
Boreal Foothills–Valley	BWBSwk1, (BWBSmw1)
Boreal Plains–Alluvial	BWBSmw2
Boreal Plains–Upland	BWBSmw1, BWBSmw2, (BWBSwk1, BWBSwk2, SWBmk)
Cariboo Mountain Foothills	SBSwk1, (ESSFwk1)
McGregor Plateau	SBSwk1, (ESSFwk2, SBSwk2)
Moist Interior–Mountain	ESSFmv1, ESSFmv3, (ESSFwk1)
Moist Interior–Plateau	SBSdk, SBSdw2, SBSdw3, SBSmc2, SBSmc3, SBSmk1, SBSmw, SBSwk3a, (SBPSdc, SBPSmc, SBSdw1, SBSmh, SBSwk1)
Moist Trench–Mountain	ESSFmm, (ESSFwc2)
Moist Trench–Valley	ICHmm, SBSdh, (ICHwk1, SBSvk)
Northern Boreal Mountains	BWBSdk1, BWBSdk2, SWBmk, (ESSFmc, ESSFmv4, BWBSmw2, BWBSwk2, BWBSwk3)
Omineca–Mountain	ESSFmc2, ESSFmv3, ESSFmv4, (ESSFwv, SWBmk)
Omineca–Valley	BWBSdk1, BWBSwk2, SBSmk1, SBSmk2, SBSwk2, SBSwk3, (ICHmc1, SBSdk, SBSmc2, SWBmk)
Wet Mountain	SBSvk, ESSFwk2, ESSFwc3, (SBSwk1, SBSwk2, ESSFmv2)
Wet Trench–Mountain	ESSFwk1, ESSFwk2, ESSFwc3, (ESSFmm)
Wet Trench–Valley	ICHwk3, ICHvk2, SBSvk, (ICHwk2, SBSwk1)

a According to the biogeoclimatic classification system (see Meidinger and Pojar 1991). For details on each biogeoclimatic unit, see regional field guides (DeLong 2003, 2004; DeLong and Meidinger 1996; DeLong et al. 1990, 1993, 1994).
b Units in brackets cover a minor (i.e., < 5%) portion of the Natural Disturbance Unit.

2 GENERAL PRINCIPLES

The guidance developed for each NDU sub-unit (NDS) was developed for management of seral stage distribution, patch size distribution, patch shape, and vegetation species composition and structure. Most of the guidance relates to approximating wildfire because, until recently, it was the key natural stand replacement disturbance agent in most NDUs (DeLong and Tanner 1996; DeLong 1998) and the one that we have exhibited the most control over. In effect, wildfire is the disturbance process we are generally attempting to replace with harvesting.

Seral Stage Distribution

Forests that differ in time since stand replacement disturbance have different structural and functional values (Franklin et al. 2002). Old-growth forests, the most obvious example of this, are considered valuable in maintaining biological diversity, as wildlife habitat, as a benchmark for forest management, and for aesthetic and intrinsic reasons (MacKinnon 1998; Vallauri et al. 2001). Recently killed forests or young natural forests also appear to provide important habitat for some organisms that are not present in young managed forest (Schmiegelow et al. 2006). For example, Black-backed Woodpeckers

(*Picoides arcticus* [Swainson]) are commonly associated with standing dead forests and may require recently burned forests for their long-term persistence (Hutto 1995; Hoyt and Hannon 2002). Certain insects and fungi appear to be either fire obligates or heavily favoured by fire (Hyvärinen et al. 2005; Buddle et al. 2006). These organisms require the burned dead trees found after fire and occur at much reduced numbers after forest salvage operations (Stepnisky 2003). Zackrisson et al. (1996) assert that the charcoal of burned snags promotes ecological processes that have important consequences for stand productivity and ecosystem function.

Achieving distribution of seral stages that is within the NRV is an important objective for ecosystem management. Focussing on young natural and old forest is appropriate since mid-aged forest is likely to be abundant in managed landscapes.

The NRV for different-age forests for each NDS was established using the estimated stand replacement disturbance cycle and a simulation model. The disturbance cycle (i.e., inverse of disturbance rate [% of total forested area per year × 100]) for each NDS was either obtained directly from DeLong (1998), if local data were available, or from adjacent forested landscapes that were assumed to have a similar disturbance history, or was based on expert opinion. Once a disturbance cycle was assigned to the NDS, the NRV for each age class was estimated using a simple stochastic landscape model implemented in SELES (Spatially Explicit Landscape Event Simulator) (Fall and Fall 2001). The model was run for 1000 years to allow the disturbance regime to reach an equilibrium. The model was then run for another 1000 years and the lowest and highest value for each age class was used to characterize the NRV.

One, or combinations, of three main strategies for management of old forest are recommended for each NDS depending on the natural disturbance cycle and the historical, temporal, and spatial distribution of old forest. In landscapes with (1) high natural disturbance rates (e.g., disturbance cycle < 150 yr), (2) generally even-aged stands dominated by early seral species, and (3) few patches of very old forest (> 200 yr) but large patches of older forest (> 120 yr), a system of "rotating reserves" is recommended. In this strategy, large patches (> 100 ha) of older forest are identified to fulfill a percentage (e.g., > 50%) of the total old forest requirements. These reserves would be scheduled for harvest when reserve area(s) of roughly equivalent value and size have been identified to take their place. Reserve value would be based on factors including age, whether the stand resulted from a natural or managed disturbance (i.e., ones from natural disturbance would have higher value since they would contain natural levels of snags and CWD), and distance from major roads. The intent is to always have some large reserves of forest that are old but not so old (e.g., > 200 yr) as to be "unnatural" and highly susceptible to stand replacement forest insect or disease outbreaks. Whenever possible, the reserves chosen to replace existing ones should be stands that originated from a natural event (e.g., wildfire) that occurred in a natural stand. Such stands are more likely to contain higher levels of deadwood and be structurally more complex than managed stands.

In landscapes where large fires were common but the disturbance cycle was roughly 150–300 years, a strategy of irregularly dispersed large permanent reserves is recommended. This may result in some areas (e.g., watersheds) having a large amount of old forest reserve and adjacent areas with much less. This strategy approximates the natural condition in these landscapes where at any one time a large fire may have consumed most of the forest in one watershed, while in an adjacent watershed much of the forest may have escaped fire for over 150 years. The more uneven-aged old forests in these landscapes are less susceptible to pest outbreaks due to uneven susceptibility of trees in the stand, and thus have a higher likelihood of maintaining old forest structure over a long time. Replacement may be necessary but not continuously, as in the rotating reserve strategy.

In landscapes where large fires were rare (i.e., fire cycle > 300 yr) and old uneven-aged forests dominate the landscape, a strategy of regularly dispersed and connected permanent reserves is recommended. In this case, all watersheds would contain a large amount of old forest. The focus would be to manage the forest in a manner that would least disrupt the matrix old forest and the functions it performs. Some amount of partial cutting may be appropriate in the matrix old forest, but only if that type of harvesting clearly maintains functionally important old-growth structures. A caution in relation to partial cutting is that access structures (e.g., roads, landings) required to conduct partial cutting may significantly reduce the ability of these harvested areas to perform the functions of the matrix old forest, especially where continued human motorized access is available.

Estimates of the patch size of old forest in natural landscapes have been shown to be heavily skewed to patches larger than 200 ha (Andison 2003). In some landscapes, where a high proportion of the landscape has been harvested, larger old forest patches are uncommon and their quality is suspect due to the effects of harvesting and road building (DeLong 2007). Studies of American marten (*Martes americana* [Turton]) and woodland caribou (*Rangifer tarandus* ssp. *caribou* [Gmelin]) indicate that they prefer landscapes with some large patches of mature forest (i.e., > 200 ha) (Chapin et al. 1998; Courtois et al. 2008). It is important to track the size of remaining old forest patches and attempt to retain the larger patches.

Young natural forest is more difficult to manage since it is hard to predict when, where, and how much young natural forest will be created on the landscape. In landscapes where there is currently an abundance of young natural forests, such as on the Moist Interior–Plateau NDS where there is an outbreak of mountain pine beetle (*Dendroctonus ponderosae* [Hopkins]), the goal may be to achieve a natural forest target made up of young natural-origin stands and old forest stands dominated by non-susceptible species. Young natural forest has been shown to be preferred habitat for Black-backed Woodpeckers when compared to other forests, including old-growth forest, at least over the first 10–20 years after initiation (Hoyt and Hannon 2002). In landscapes (i.e., NDSs) where there is limited stand replacement disturbance due to fire control, limiting management (i.e., harvest and/or planting) of smaller patches of young forest killed by natural events is suggested. However, if these strategies continue to result in young natural forest amounts well below historic levels, a longer term strategy that includes prescribed burning may be required.

Intensive forest management may be used as a tool to increase the area available for maintaining natural forests by reducing the land base required to achieve a desired harvest yield. Any strategy that can improve the volume yield for particular sites means that a desired harvest level can be achieved from a smaller land base, resulting in more area that can be used to protect natural forest values. This strategy has particular merit in areas where sites are very productive and easily managed, such as the Wet Trench NDU (Figure 1).

Patch Size Distribution, Block Design, and Species Composition and Structure

Managing for a more natural patch size distribution that would include a large proportion of harvested forest in patches exceeding 100 ha appears to have some important ecological benefits. Apart from resulting in a more natural spatial age mosaic on the landscape, it slows the rate of new road building, new stream crossings, and snag depletion (DeLong et al. 2004). Allowing some large patches also reduces fragmentation, which has been shown to have a negative impact on species such as American marten (Chapin et al. 1998; Hargis et al. 1999) and woodland caribou (Smith et al. 2000).

In landscapes where fire control has had a significant impact (i.e., all landscapes within the study area, based on the last 40 years of fire records), this control will have reduced large patches but increased small patches since it stops some small fires from getting larger. In these areas, it is suggested that harvested patches should be designed to take the place of medium to large disturbance patches that historically were created by fire. Small patches can be effectively managed by not harvesting small patch disturbances or harvesting only within their boundaries.

Harvesting cannot completely duplicate the effects of fire but it can approximate certain characteristics of fire such as size, shape, and fire skips. Some other characteristics such as variable disturbance intensity can be partially managed for.

The shape of fires is more complex than past harvest openings (DeLong and Tanner 1996). Table 2 contains suggested targets for block shape complexity based on wildfires examined by DeLong and Tanner (1996). In the past, it was not practical to lay out blocks with complex shapes using compass and chain. However, global positioning systems and geographic information systems allow for the practical implementation of more complex block shapes. DeLong (1999)has detailed information on design of blocks to approximate wildfire.[3]

Fire skips are consistently found within the boundaries of fires (Eberhart and Woodward 1987; DeLong and Tanner 1996) and appear to be an important landscape element in disturbed landscapes (DeLong and Kessler 2000). The ecological importance of retaining mature forest patches or individual trees within clearcuts has been demonstrated for various organisms (Sillett and Goslin 1999; Tittler et al. 2000; Côté and Ferron 2001). Currently, an average of approximately 10% of the area within a harvest opening is left in fixed-width riparian reserves or wildlife tree patches within the study area. Increasing the proportion of harvest area left in reserves and the average reserve size as forest harvest patch size increases is recommended, consistent with the trend demonstrated for wildfires (DeLong and Tanner 1996).

TABLE 2 *Recommended shape index for different size openings*

Opening Size (ha)	Shape Index* Target
50–100 ha	1.5–2.5
100–500 ha	2–3.5
>500 ha	>2.5

* Shape index = $\dfrac{P}{3.545\bullet\sqrt{A\bullet 10000}}$ where P = perimeter (m), A = area (ha).

3 C. DeLong. 1999. Natural disturbance block design workbook. B.C. Min. For., Prince George, B.C. Unpubl. internal report. 16 p.

Wildfire intensity varies considerably over the extent of a wildfire event. The impact within a fire boundary can vary from none (i.e., fire skips) to considerable, where all trees are killed and most of the forest floor is removed. This variation in intensity provides for considerable variation in vegetation pattern (Carleton and MacLellan 1994; Schimmel and Granstrom 1996). In fire skips, the vegetation will remain relatively unchanged, whereas in other areas, the resulting vegetation is a product of remaining live plant tissue, buried live seed, seed transported from adjacent live seed sources, and site conditions. Any attempt to create similar vegetation patterns after harvest will be crude but similar proportions of non-forest (e.g., willow, alder) and forested habitat types and forests of similar tree composition and structure are suggested.

The following sections provide detailed information on the NDSs.

3 BOREAL FOOTHILLS

Location, Climate, and Vegetation

This unit occupies the valleys and mountain slopes on the lee side of the Rocky Mountains in the Hart Foothills and Peace Foothills Ecosections. This NDU occurs in a relatively narrow band from 54 to 56° N latitude. The unit occurs from the valley bottoms to alpine peaks, above the Boreal Plains NDU to the east and adjacent to the Wet Mountain NDU to the west.

The climate of this unit is characterized by frequent outbreaks of arctic air masses, resulting in long, cold, snowy winters and short summers. This unit is intermediate in precipitation but one of the coldest NDUs. Mean annual precipitation ranges from 560 to 780 mm and mean annual temperature from −0.3 to 0.4°C.

Upland climax forests are dominated by hybrid white spruce (*Picea glauca* (Moench) Voss) and/or occasionally subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Subalpine fir increases with elevation. Lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. *ex* Loud.) and to a lesser extent trembling aspen (*Populus tremuloides* Michx.) and paper birch (*Betula papyrifera* Marsh.) dominate young stands. Black spruce (*Picea mariana* (P. Mill.) B.S.P) occurs sporadically along with lodgepole pine on upland sites.

Wetlands are uncommon but do occur scattered along the broader valleys and in flatter terrain in the mountains.

Alluvial forests of balsam poplar (*Populus balsamifera* L. ssp. *balsamifera*), often with a minor component of spruce, are found sporadically along the floodplains of the larger rivers.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit. The fire cycle assigned to this unit is 120 and 150, respectively, for the valley (BWBSmw1, SBSwk2) and mountain (BWBSdk1, ESSFmv2) sub-units. Table 3 shows the amount of forests of different age that would be associated with these fire cycles. Large wildfires (>1000 ha) dominated the landscape, and upland sites were generally regenerated quickly by dense lodgepole pine stands, resulting in large patches of relatively even-aged forests (Table 3). Black spruce and white spruce regenerated the wetland areas after fire. Stand ages occasionally exceed 200 years, and relatively large patches (>100 ha) of

TABLE 3 *Estimates of statistics relatin*

Natural Disturbance Unit	Stand replacement disturbance cycle[a]	Time since disturbance distribution[b] (% of total forest area)				Patch size (ha) (% of total disturbance area)[c]				Disturbance type (% of disturbance area)[d]	
		>250 yr	>140 yr	>100 yr	< 40 yr	>1000	101–1000	51–100	< 50	Stand replacement	Gap replacement[e]
Boreal Foothills–Mountain	150	15–25	33–49	43–62	19–36	40	30	10	20	80	20
Boreal Foothills–Valley	120	8–17	23–40	33–55	19–45	40	30	10	20	90	10
Boreal Plains–Alluvial	200[d]	23–37	41–61	52–72	12–33	0	0	40[d]	60[d]	80	20
Boreal Plains–Upland	100	6–12	17–33	28–49	25–50	70	20	5	5	98	2
Cariboo Mountain Foothills	400	47–59	65–74	71–81	8–18	40	30	15	15	80	20
McGregor Plateau	220	26–39	43–61	54–72	13–31	40	45	5	10	90	10
Moist Interior–Mountain	200	23–37	41–61	52–72	12–33	40	30	10	20	70	30
Moist Interior–Plateau	100	6–12	17–33	28–49	25–50	70	20	5	5	98	2
Moist Trench–Mountain	300	39–50	58–69	66–77	10–22	60	30	5	5	70	30
Moist Trench–Valley	150	15–25	33–49	43–62	19–36	70	20	5	5	90	10
Northern Boreal Mountains	180[d]	20–35	37–60	48–70	12–34	60[d]	30[d]	5[d]	5[d]	70	30
Omineca–Mountain	300	39–50	58–69	66–77	10–22	40	30	10	20	70	30
Omineca–Valley	120	8–17	23–40	33–55	19–45	60	30	5	5	95	5
Wet Mountain	900	74–80	84–89	88–93	3–7	10	60	10	20	40	60
Wet Trench–Mountain	800	70–77	80–88	83–92	4–11	10[d]	60[d]	10[d]	20[d]	40	60
Wet Trench–Valley	600	63–72	76–84	81–90	4–11	10[d]	60[d]	10[d]	20[d]	60	40

a Disturbance cycles are the inverse of disturbance rate (% of total forested area/yr) × 100. Unless noted in the text, disturbance rates were derived using methodology outlined in DeLong (1998) and generalized for the NDU.

b This is the range in percent of the total forested area within the NDU that has not had a stand replacement event for the specified time period, estimated to be present at any one time. See Section 2 for details on how the estimate was determined.

c Patch size distributions were estimated using methodology outlined in DeLong (1998) except where noted in the table.

d Based on expert opinion. Methods in DeLong (1998) could not be used since much of the area has been burned by prescribed fire so natural pattern is obscured.

e Disturbance openings caused by death of individual trees or small groups of trees. Gaps are generally < 1 ha and remove < 40% of the basal area of a stand.

older forest (120–180 yr) could be found scattered across the landscape (D. Rosen, unpublished data). The amount of old forest in any particular watershed would have varied considerably over time. Recent fires may have removed most of the old forest in some watersheds whereas others may have not experienced large fires for hundreds of years.

During stand development, increasing amounts of white spruce and subalpine fir will occur in stands originally dominated by lodgepole pine. The increase occurs more rapidly and these species are more abundant on wetter sites and at higher elevations. Post-fire stands are very dense except on the wettest sites, and these stands generally self-thin over time. No data for snags and CWD are currently available for this unit.

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has slowed the natural disturbance rate. This has had the compound effect of increasing the amount of old forest in more remote areas where harvesting has not occurred and reducing young forest established by fire.

Dispersed mid-sized patch (60–100 ha) harvesting has been the dominant pattern of harvest. Dispersed harvest of mid-sized patches not only creates a very unnatural landscape pattern but also increases fragmentation and results in a porous landscape for the spread of pests such as mountain pine beetle (MPB).

Recommended Practices

Old forest Since forests with "old forest characteristics" were typically dispersed unevenly across the NDU (i.e., rare in some watersheds but abundant in others), old forest targets could be met over multiple watersheds rather than in each watershed. Table 3 contains estimates of the NRV of the time since the last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of natural disturbances should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size Since medium-sized patches (50–100 ha) are rare in the natural landscape and small patches are still naturally created by small fires, windthrow, and root disease, the emphasis should be on creating larger patches (> 100 ha). Larger patches should be created by aggregating recent blocks in areas previously harvested and/or by designing new large blocks in unharvested areas. Patch size distribution should emulate that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[4]

Stocking and stand structure Stand density in young circumesic stands (< 40 yr) should generally be kept at total stocking levels of > 2000 stems per hectare (sph) to approximate dense natural stands. More open patchy stocking (i.e., < 1000 sph) on hygric sites is recommended. Even-aged stands over most of the landscape would approximate the natural pattern. In areas of mixed aspen and spruce, efforts should be made to grow mixed stands similar to those that would have developed under a natural fire regime.

4 DeLong (1999).

Location, Climate, and Vegetation

This unit occupies the gently rolling terrain of the Taiga Plains and Boreal Plains Ecoprovinces. This NDU is found over a wide geographic range from 54 to 60° N latitude and from 119 to 123° W longitude. The unit generally occurs from the valley bottoms to 900–1100 m elevation, below the Boreal Foothills NDU in the south and Northern Rockies NDU in the north.

The northern continental climate of this unit is characterized by frequent outbreaks of arctic air masses, resulting in long, very cold winters and short summers. However, due to long day length in the summer, forest productivity is similar to areas farther south. This is the driest NDU in the region with mean annual precipitation ranging from 330 to 570 mm, with 35–55% falling as snow. It is the coldest lower elevation NDU. Mean annual temperature ranges from −2.9 to 2.0°C. The ground freezes for a large part of the year, and discontinuous permafrost is common in the northeastern parts of this NDU.

Upland climax forests are dominated by white spruce and/or black spruce depending on topographic position and time since last stand replacement disturbance. It is theorized that in the absence of a stand replacement event, stand productivity will drop and the proportion of black spruce will increase in response to reductions in soil temperatures and nutrient cycling due to the buildup of the forest floor. Trembling aspen and to a lesser extent lodgepole pine and paper birch dominate young stands. Mixed forests of trembling aspen and white spruce are very common except in areas where the spruce seed source has been removed due to land clearing.

Wetlands are very common and diverse, especially in the northern portion of this NDU. There are seven forested and nine non-forested wetland types recognized within this NDU. Black spruce or tamarack (*Larix larciana* (Du Roi) K. Koch) dominates the forested wetlands. Non-forested wetlands are most commonly dominated by speckled alder (*Alnus incana* L.), scrub birch (*Betula nana* L.), Alaska paper birch (*Betula neoalaskana* Sarg.), willows (*Salix* spp.), sedges (*Carex* spp.), or buckbean (*Menyanthes trifoliata* L.).

Alluvial forests of balsam poplar, often with a minor component of spruce, are common along the floodplains of the larger rivers. Natural grassland and shrub-steppe occur on steep, south-facing slopes, especially above some of the major rivers such as the Peace.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit with the exception of the broad alluvial terraces adjacent to the larger rivers. The disturbance rate[5] for the upland portions of this unit is estimated to be about 1%[6] of the total forested area per year and has been assigned a fire cycle of 100 years. Table 3 shows the amount of forests of different age that would be associated with this fire cycle. Large wildfires (> 1000 ha) dominated the landscape, and upland sites were regenerated quickly by dense trembling aspen, and spruce or lodgepole pine, resulting in large patches of relatively even-aged forests (Table 3). Black spruce, tamarack, Alaska paper birch, and white spruce regenerated the wetland areas after fire. The wetland stands tend to be very open and fill in over time except where they are verging on upland areas, in which case they can be denser. Small areas where fire was intense

5 All disturbance rates are for stand replacement wildfire except where noted.
6 Estimate based on calculation shown in the Introduction.

may regenerate to willow or alder (C. DeLong, unpublished data). Tomentosus root disease (*Inonotus tomentosus* (Fr.:Fr.) S. Teng.) is felt to be a key disturbance agent affecting white spruce, and in some localized areas, may cause conversion from spruce-dominated stands to aspen-dominated stands over 20–40 years (R. Reich, pers. comm., B.C. Ministry of Forests and Range, Prince George, Regional Pathologist). Eastern spruce budworm (*Choristoneura fumiferana* Clemens) may also cause significant mortality of mature or immature spruce and lead to conversion of mixed to more pure aspen stands. Stand ages rarely exceeded 200 years. Relatively large patches (>100 ha) of older forest (140–180 yr) were found scattered across the landscape but more recently have been reduced by harvesting (D. Rosen, unpublished data). Although patches of old forest (>140 yr) likely always occurred in the landscape, their position would have moved around the landscape over time. Within the boundaries of the fires, 3–15% of total area of the fire can be composed of unburned mature forest remnants (Eberhart and Woodward 1987).

During stand development, increasing amounts of white spruce and black spruce will occur in many stands originally dominated by trembling aspen or lodgepole pine. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites. Post-fire stands are very dense except on the wettest sites and they self-thin over time. Density of snags for aspen mixedwood stands is likely similar to that reported in Lee et al. (1995). They report snag densities (± S.E.M.) of 33.0 ± 6.8, 73.1 ± 11.3, and 66.2 ± 9.1 snags per hectare (≥10 cm dbh) for young (20–30 yr), mature (50–65 yr), and old (120+ yr) stands, respectively. For 90- to 150-year-old stands near Fort Nelson, Kabzems (2001) reports snag densities of 71–168 snags per hectare.

CWD volumes of aspen mixedwood stands are likely similar to those reported in Lee et al. (1995). They report total CWD volumes (± S.E.M.) of 108.8 ± 5.1, 109.1 ± 7.6, and 124.3 ± 7.1 m^3/ha for young (20–30 yr), mature (50–65 yr), and old (120+ yr) stands, respectively.

Stand replacement flood cycles along the major rivers in this NDU are unknown. Until data are available, a stand replacement disturbance cycle of 200 years has been assigned to the alluvial portions of this NDU based on expert opinion (Table 3). Disturbance patches are thought to be <100 ha (Table 3). There is a typical floodplain succession from willow to cottonwood on the lower benches and from cottonwood to spruce on the higher benches.

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has slowed the natural disturbance rate. This has had the compound effect of increasing the amount of old forest in more remote areas where harvesting has not occurred and reducing young forest established by fire.

Dispersed mid-sized patch (60–100 ha) harvesting has been the dominant pattern of harvest. Dispersed harvest of mid-sized patches is very unnatural and creates fragmentation and a porous landscape for the spread of pests that attack older trees.

Land clearing for agriculture, range, and forestry has removed mature spruce forest from many areas, resulting in a loss of natural spruce regeneration. This, along with silvicultural practices aimed at regenerating spruce or aspen but not both, has lead to a shift in natural tree species distribution patterns.

Well site clearing and clearing of seismic lines associated with the oil and gas industry has resulted in fragmentation of the landscape and allows increased human access into remote areas of this NDU.

Concentrated harvesting along the alluvial benches of the major rivers has almost certainly reduced the amount of old forest in these areas.

Recommended Practices

Old forest Since older forests (i.e., 120–200 yr since last disturbance) are estimated to have been consistently present in this NDU, a system of rotating old forest reserves in this age range is appropriate. This would ensure stands with "old forest characteristics" exist but are not unnaturally old and more susceptible to pest infestation. Large patches (> 100 ha) of old forest should be identified and recruited such that replacement areas > 120 years old are available to replace areas > 150 years of age that would be harvested. Recruitment areas should be preferentially selected in the following order: (1) older natural stands (e.g., unsalvaged wildfires), (2) older semi-natural stands (e.g., partially salvaged wildfires), (3) large harvest blocks designed to approximate wildfire that have mostly been regenerated naturally, (4) large harvest blocks (> 100 ha) designed to approximate wildfire that have mostly been regenerated artificially, (5) large harvest blocks (> 100 ha) that were not designed specifically to approximate wildfire, and (6) small- to medium-sized harvest blocks (< 100 ha). Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of natural disturbances should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size Since medium-sized patches (50–100 ha) are rare in the natural landscape and small patches are still naturally created by small fires, windthrow, and root disease, the emphasis should be on creating larger patches (> 100 ha). Larger patches should be created by aggregating recent blocks in areas previously harvested and/or by designing new large blocks in unharvested areas. Patch size distribution should emulate that of wildfire (Table 3) as closely as possible. Design of blocks should follow guidance in DeLong.[7] A recognized limitation to creating large harvest openings in this NDU is the large extent of non-commercial forest and non-forest area (i.e., poor pine forests, wetlands).

Stocking and stand structure Stand density in young circumesic stands (< 40 yr) should generally be kept at total stocking levels of > 2000 sph to approximate dense natural stands. More open patchy stocking (i.e., < 1000 sph) on hygric sites is recommended. Even-aged stands over most of the landscape would approximate the natural pattern. In areas of mixed aspen and spruce, efforts should be made to grow mixed stands similar to those that would have developed under a natural fire regime (Chen and Popadiouk 2002; Redburn and Strong 2008).

7 DeLong (1999).

Location, Climate, and Vegetation

This unit occupies the Willow River drainage north to where the Cariboo Mountains end. It is situated between the Moist Interior and Wet Mountain NDUs and below the McGregor Plateau NDU.

This unit is one of the wetter NDUs but is intermediate in temperature. Mean annual precipitation is 899 mm and mean annual temperature 2.7°C. Mean annual snowfall is in the range of 3 m.

Upland climax forests are dominated by hybrid white spruce (P*icea glauca* x *engelmannii* (Moench) Voss var. (Parry *ex* Engelm. Boivin) with varying amounts of subalpine fir. Lodgepole pine and to a lesser extent trembling aspen and paper birch dominate young stands. Douglas-fir (*Pseudotsuga menziesii* (Mirbel) Franco) is a long-lived seral species occurring on drier sites, particularly in areas of colluvial soils or bedrock control. Black spruce occurs sporadically along with lodgepole pine on upland sites.

Wetlands are locally common, especially along the Willow River.

Alluvial forests of black cottonwood (*Populus balsamifera* L. ssp. *trichocarpa*) , often with a minor component of spruce, are found mainly along the Willow River.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit. The stand replacement disturbance cycle assigned to this unit is 400. Table 3 shows the amount of forests of different age that would be associated with this fire cycle. Large wildfires (> 1000 ha) dominated the landscape, and upland sites were generally regenerated quickly by dense lodgepole pine stands, resulting in large patches of relatively even-aged forests (Table 3). Black spruce and white spruce regenerated on wetter sites after fire. Young Douglas-fir stands can be found occasionally on drier slopes where larger Douglas-firs have escaped fire. Stand ages often exceed 200 years, and large patches (> 100 ha) of older forest (120–180 yr) could be found commonly across the landscape.

Spruce beetle (*Dendroctonus rufipennis* (Kirby)), tomentosus root rot, and 2-year-cycle budworm (*Choristoneura biennis* (Freeman)) may occasionally cause significant within-stand mortality in spruce and subalpine fir leading stands. Tomentosus root rot is generally restricted to lower elevations (< 900 m).

During stand development, increasing amounts of white spruce and subalpine fir will occur in stands originally dominated by lodgepole pine. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites and at higher elevations. Post-fire stands are very dense except on the wettest sites and they self-thin over time. No data for CWD or snags are currently available for this unit.

Forest Management Effects

A relatively long and extensive history of harvesting (i.e., > 50 yr) has taken place in this NDU due to the stands being dominated by spruce, to high wood volume and quality, and to proximity of the wood to mills. More recently, harvesting of bark beetle impacted stands has further reduced the amount of natural forest.

Effective fire control over the past 40–50 years has reduced the number of large fires, resulting in the slowing of the natural disturbance rate and less young fire origin forest.

Much of the early harvesting was partial cutting (i.e., intermediate utilization), which has increased the component of subalpine fir while reducing hybrid spruce.

Harvest patch size in this NDU is varied but there is a large area of patches >1000 ha. Many of the blocks are very regular (i.e., rectangular) in shape, thus reducing the amount of edge available. Due to extensive harvest, very few larger patches of old forest remain, thus reducing the amount of old interior forest.

Recommended Practices

Old forest Since forests with "old forest characteristics" dominated the landscape in this NDU, old forest reserves should be well distributed throughout all watersheds. A high degree of connectivity between these old forest patches should also be managed since there was always a high degree of connectivity of old forest in the natural landscape. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of natural disturbances should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size Patch size distribution is currently weighted towards very large openings due to extensive harvesting in the 1960s. A more natural patch size distribution with a larger number of openings in the 100- to 1000-ha patch size can be addressed only during second pass harvesting. Patch size distribution should emulate that of wildfire (Table 3) as closely as possible. Design of blocks should follow guidance in DeLong.[8]

Stocking and stand structure Past intermediate utilization logging has increased the amount of subalpine fir in these stands. This, along with extensive planting of lodgepole pine, has likely decreased the amount of hybrid spruce in the landscape. Stocking levels are likely reasonably close to natural stands. More open patchy stocking (i.e., <1000 sph) on hygric sites is recommended.

6 McGREGOR PLATEAU

Location, Climate, and Vegetation

This unit occupies the rolling plateau east of the Crooked River, west to the Rocky Mountains, and between 54 and 55° N latitude. It is situated between the Moist Interior and Wet Mountain NDUs.

This unit is one of the wetter NDUs but is intermediate in temperature. Mean annual precipitation is 899 mm and mean annual temperature is 2.7°C. Mean annual snowfall is in the range of 3 m.

Upland climax forests are dominated by hybrid white spruce with varying amounts of subalpine fir. Lodgepole pine, and to a lesser extent trembling aspen and paper birch, dominate young stands. Douglas-fir is a long-lived seral species occurring on drier sites, particularly in areas of colluvial soils or bedrock control. Black spruce occurs sporadically along with lodgepole pine on upland sites.

8 DeLong (1999).

Wetlands are locally common, especially along the Parsnip River.

Alluvial forests of black cottonwood, often with a minor component of spruce, are found mainly along the Parsnip River.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit. The stand replacement disturbance cycle assigned to this unit is 220. Table 3 shows the amount of forests of different age that would be associated with this fire cycle. Large wildfires (> 1000 ha) dominated the landscape, and upland sites were generally regenerated quickly by dense lodgepole pine stands, resulting in large patches of relatively even-aged forests (Table 3). Black spruce and white spruce regenerated on wetter sites after fire. Young Douglas-fir stands can be found on drier ridges where larger Douglas-firs have escaped fire. Stand ages often exceed 200 years, and large patches (> 100 ha) of older forest (120–180 yr) could be found scattered across the landscape. Although large patches of old forest (> 140 yr) likely always occurred in the landscape at any one time period, old forest may be rare in any particular area due to the extent of the fires (> 1000 ha).

Spruce beetle, tomentosus root rot, and 2-year-cycle budworm may occasionally cause significant within-stand mortality in spruce and subalpine fir leading stands. Tomentosus root rot is generally restricted to lower elevations (< 900 m).

During stand development, increasing amounts of white spruce and subalpine fir will occur in stands originally dominated by lodgepole pine. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites and at higher elevations. Post-fire stands are very dense except on the wettest sites and they self-thin over time. No data for CWD or snags are currently available for this unit.

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has slowed the natural disturbance rate by reducing the number of large fires. This has had the compound effect of increasing the amount of old forest in more remote areas where harvesting has not occurred and reducing young forest established by fire.

Some organisms appear to be heavily dependent on fire-killed forests. Hutto (1995), in a study of bird communities following stand replacement fires in the Rocky Mountains of Montana, found that Black-backed Woodpeckers were generally restricted in their habitat distribution to standing dead forests created by stand replacement fires. The populations of certain beetles that are red-listed in Scandinavia are enhanced by fire (Hyvärinen et al. 2005). These organisms require the burned dead trees found after fire and occur at much reduced numbers after forest salvage operations (Schmiegelow et al. 2006).

While wildfire creates disturbances of all sizes and the landscape is dominated by large disturbances, forest management has generally been directed to achieve mid-sized patches (40–100 ha) (DeLong and Tanner 1996). Larger harvest patches often occur due to management of windthrow. Dispersed harvest of mid-sized patches is both unnatural and creates fragmentation and a porous landscape for the spread of pests that attack older trees.

Recommended Practices

Old forest Since forests with "old forest characteristics" were typically dispersed unevenly across the NDU (i.e., rare in some areas but abundant in others), old forest targets could be met over multiple watersheds rather than in each watershed. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of natural disturbances should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size Since medium-sized patches (50–100 ha) are rare in the natural landscape and small patches are still naturally created by small fires, windthrow, and root disease, the emphasis should be on creating larger patches (> 100 ha). Larger patches should be created by aggregating recent blocks in areas previously harvested and/or by designing new large blocks in unharvested areas. Patch size distribution should emulate that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[9]

Stocking and stand structure Current species composition and stocking in young managed stands appear to be consistent with natural patterns. Stand density of young circumesic stands (< 40 yr) should generally be kept at total stocking levels of > 2000 sph to approximate dense natural stands. More open patchy stocking (i.e., < 1000 sph) on hygric sites is recommended. Even-aged stands over most of the landscape would approximate the natural pattern.

7 MOIST INTERIOR

Location, Climate, and Vegetation

This unit occupies the gently rolling terrain and broad mountain peaks of the Fraser Plateau and the Fraser Basin Ecoregions. This NDU is found over a wide geographic range from 53 to 55° N latitude and from 122 to 125° W longitude. The elevation range of this NDU is 600–1800 m but most of it lies between 700 and 1200 m.

The climate of this unit is continental and is characterized by seasonal extremes of temperature; severe, snowy winters; relatively warm, moist, and short summers; and moderate annual precipitation (Meidinger and Pojar 1991). Excluding the Boreal Plains, this NDU is drier than the other NDUs in the region. It is intermediate in temperature between the colder montane and northern units and warmer trench units. Mean annual temperature for most of this unit ranges from 0.6 to 3.7°C. Average temperature is below 0°C for 4–5 months of the year, and above 10°C for 2–5 months. Mean annual precipitation data from long-term stations range from 481 to 727 mm, of which perhaps 25–50% is snow. Higher elevation mountains in the unit likely have a more severe climate (i.e., lower temperatures, more precipitation, more snow), but no data are available for these areas.

The Moist Interior NDU has been subdivided into a lower elevation Plateau sub-unit that corresponds to the Sub-Boreal Spruce zone and a higher elevation Mountain sub-unit that corresponds to the Engelmann Spruce–Subalpine

9 DeLong (1999).

Fir zone due to differences in climate, vegetation, and natural disturbance patterns.

Upland coniferous forests dominate the Moist Interior–Plateau landscape. Hybrid white spruce and subalpine fir are the dominant climax tree species. Lodgepole pine is very common in mature forests throughout the unit, and both lodgepole pine and trembling aspen are pioneers in the extensive seral stands. Paper birch is another pioneer tree found most often on moist, rich sites. Douglas-fir is usually a long-lived seral species, occurring most abundantly on dry and warm sites in the southeastern part of the NDU. Black spruce also occurs in climax upland forest in combination with lodgepole pine on sites with restricted rooting.

In the Moist Interior–Mountain landscape, upland climax forests have a higher subalpine fir component. Douglas-fir, paper birch, and trembling aspen are generally absent in this sub-unit, with the exception of some warmer slopes.

Alluvial forests of black cottonwood, often with a minor component of spruce, occur to a limited extent on active floodplains of the major streams and rivers. Wetlands are common and dot the landscape in poorly drained post-glacial depressions or river oxbows.

Wetland community types include sedge marshes; shrub fens of scrub birch, swamp birch (*Betula pumila* L.), and willows; treed fens and swamps with black and hybrid white spruce; and black spruce bogs. Acidic, nutrient-poor bogs are less common than the richer wetland types (marshes, fens, and swamps). Tamarack occurs in a number of wetlands south of the Nechako River.

Natural grassland and shrub-steppe are uncommon in this NDU, occurring on some warm, dry sites scattered in the major valleys.

Natural Disturbance Ecology

Fire and mountain pine beetle are the key stand replacement disturbance agents operating in this unit. The disturbance rate[10] for the plateau and mountain portions of this unit is estimated to be 0.75–1.25% [11] and 0.48% of the total forested area per year, respectively (DeLong 1998). The disturbance cycles assigned to the plateau and mountain portions are 100 and 200, respectively, based on work conducted by Andison (1996) and DeLong (1988). Table 3 shows the estimated NRV in amount of different age forests that would be associated with this fire cycle. Large wildfires (>1000 ha) dominated the landscape, and sites were regenerated quickly by dense lodgepole pine and/or trembling aspen stands, resulting in large patches of relatively even-aged forests (Table 3). Minor amounts of young white and/or black spruce forest could be found in wetter patches within the fire boundaries often adjacent to unburned mature forest. Young Douglas-fir stands occur on drier ridges near larger Douglas-fir fire remnants. Small areas where fire was intense may regenerate to willow or alder (C. Delong, unpublished data). Stand ages rarely exceeded 200 years except in the more mountainous areas, but relatively large patches (>100 ha) of older forest (140–180 yr) could be found scattered across the landscape (Andison 1996; DeLong and Tanner 1996). Although large patches of old forest (>140 yr) generally occurred in the landscape, their position would have moved around the landscape over

10 All disturbance rates are for stand replacement wildfire except where noted.
11 All estimates quoted are for the period of 1911–1930 because these were deemed to more accurately reflect the true natural disturbance rate.

time. Within the boundaries of the fires, 3–15% of the total area of the fire can be composed of unburned mature forest remnants (DeLong and Tanner 1996). These mature forest remnants are distributed throughout all landscape positions, including flat lodgepole pine stands (DeLong and Tanner 1996). Very little remnant structure exists outside of these patches. Data from DeLong and Tanner (1996) indicate that there was < 1 live remnant tree per hectare outside of remnant patches. More live remnant trees likely occur in areas with a higher component of Douglas-fir due to their increased ability to survive fire, but this has not been documented.

During stand development, increasing amounts of white spruce, black spruce, and subalpine fir will occur in stands originally dominated by lodgepole pine or trembling aspen. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites. Douglas-fir will be co-dominant where established with lodgepole pine. Post-fire stands are very dense except on the wettest sites and then self-thin over time (Table 4). Density of snags > 7.5 cm dbh generally exceed 100 sph and are most abundant in mature stands due the effect of self-thinning (Table 4). Larger diameter trees and snags (> 15 cm dbh) are most abundant in stands exceeding 140 years of age but do occur in stands of all ages (Table 4).

Coarse woody debris volume ranges considerably in response to the time since the last fire, age of the stand at time of the fire, and number of times it has burned (Table 5). Fires may burn over the same area 2–3 times within a short period (< 50 yr) leaving very little dead wood on the ground. CWD volumes are highest in young stands due to the large amount of wood that is left over from the previous stand (Table 4). Very little of the main stem wood of mature live trees is actually consumed by fire, and standing snags are mostly down after 40 years. Thus, most of the standing live tree biomass ends up as CWD.

Within this NDU, there is no documented evidence that MPB played a major role as a stand replacement agent before fire control. Based on the known regeneration dynamics of the tree species present, MPB-origin stands would be presently an open multi-aged mix of lodgepole pine, white spruce, and subalpine fir.

TABLE 4 *Means and standard deviations (in brackets) of selected stand characteristics for young matrix (40–70 yr), mature matrix (70–140 yr), remnant patch, and old matrix forest (>140 yr) stand types. Representative of lodgepole pine stands in the Moist Interior–Plateau NDU (data adapted from DeLong and Kessler 2000 for stands in SBSmk1).*

	Stand type			
Stand characteristics	**Young**	**Mature**	**Remnant**	**Old**
Tree density	2597 (471)	1910 (780)	1165 (394)	984 (263)
Snag density	268 (198)	460 (193)	158 (78)	170 (72)
>15 dbh tree density	408 (273)	860 (189)	693 (171)	698 (215)
>25 cm dbh tree density	9 (11)	59 (55)	221 (90)	334 (99)
>15 cm dbh snag density	12 (17)	59 (52)	73 (45)	126 (54)
>25 cm dbh snag density	3 (5)	2 (5)	15 (17)	31 (27)
# of cavities per hectare	13 (18)	9 (11)	30 (34)	18 (20)
Average tree dbh (cm)	11.3 (1.2)	15.4 (1.9)	17.7 (3.7)	20.8 (3.3)

TABLE 5 *Summary statistics for coarse woody debris volume for young matrix, remnant patch, mature matrix, and old matrix stand types (n = 10). Representative of lodgepole pine stands in the Moist Interior–Plateau NDU (data from DeLong and Kessler 2000 for stands in SBSmk1).*

	Total			< 17.5 dbh		> 17.5 dbh	
Stand type	**Mean**	**Range**	**SD**	**Mean**	**SD**	**Mean**	**SD**
Young matrix	261.8	5.6–590.3	201.3	76.0	54.7	188.5	177.3
Remnant patch	229.2	33–393.4	116.4	104.8	46.7	124.2	86.5
Mature matrix	174.4	23.4–283.3	90.5	71.8	37.5	84.1	74.6
Old matrix	192.6	38.6–286	78.7	82.5	37.6	112.8	61.5

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has slowed the natural disturbance rate from 0.8 to 0.008% of the total forested area per year in the SBSmk1 plateau portion of this NDU (DeLong and Tanner 1996). This reduction appears to be reasonably representative of the whole NDU based on lack of recent fires. Over the whole NDU, this has had the compound effect of increasing the amount of old forest in more remote areas where harvesting was not occurring (e.g., south end of Vanderhoof District) and reducing young forest established by fire. Increasing old forest that is the most susceptible to MPB and decreasing the amount of large patches of young forest that is least susceptible to MPB in some remote areas has likely exacerbated the current MPB infestation.

Some organisms appear to be heavily dependent on fire-killed forests. Hutto (1995), in a study of bird communities following stand replacement fires in the Rocky Mountains of Montana, found that Black-backed Woodpeckers were generally restricted in their habitat distribution to standing dead forests created by stand replacement fires. The populations of certain beetles that are red-listed in Scandinavia are enhanced by fire (Hyvärinen et al. 2005). These organisms require the burned dead trees found after fire and occur at much reduced numbers after forest salvage operations (Schmiegelow et al. 2006).

While wildfire creates disturbances of all sizes and the landscape is dominated by large disturbances, forest management has generally been directed to achieve mid-sized patches (40–100 ha) (DeLong and Tanner 1996). Larger harvest patches often occur due to management of beetle or windthrow. Dispersed harvest of mid-sized patches not only creates a very unnatural landscape pattern but also increases fragmentation and results in a porous landscape for the spread of pests such as MPB.

Currently, disturbance rates associated with harvesting are similar to those previously associated with wildfire. However, harvesting removes old forest at a faster rate than wildfire because harvesting concentrates on stands > 100 years of age whereas wildfire is relatively unselective as to the age of stand it will burn.

Dense stands of lodgepole pine were typical after wildfire. The lowest stocking level found for young natural stands (50 yr) in the SBSmk1 was 2224 sph > 7.5 dbh (Table 4) (DeLong 1998). Managed stands vary considerably in density depending on whether natural or artificial regeneration is used and the rate of ingress from naturally regenerated stems. B.C. Ministry of Forests and Range records for young managed stands in the SBSmk1 indicate stocking levels of 500–21 000 sph (average 3475 sph). Certain practices such as low impact site preparation, which limits mineral soil exposure, in combination with modest stocking levels (< 1600 sph), may result in some stands being outside the natural range of variability in stocking level, but this remains to be examined.

Recommended Practices

Old forest Since older forests (i.e., 120–200 yr since last disturbance) are estimated to have been consistently present but very old forests (> 250 yr since last disturbance) were rare in the plateau portion of this NDU, a system of rotating old forest reserves in this age range is appropriate. This would ensure stands with "old forest characteristics" exist but that the stands are not unnaturally old and more susceptible to pest infestation. Large patches (> 100 ha) of old forest should be identified and recruited such that replacement areas > 120 years old are available to replace areas > 150 years of age that would be harvested. Recruitment areas should be preferentially selected in the following order: (1) older natural stands (e.g., unsalvaged wildfires), (2) older semi-natural stands (e.g., partially salvaged wildfires), (3) large harvest blocks designed to approximate wildfire that have mostly been regenerated naturally, (4) large harvest blocks (> 100 ha) designed to approximate wildfire that have mostly been regenerated artificially, (5) large harvest blocks (> 100 ha) that were not designed specifically to approximate wildfire, and (6) small- to medium-sized harvest blocks (< 100 ha). Fixed reserves may be more appropriate in the mountain portions of the NDU but may be augmented with some level of floating reserve. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of wildfires should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands. It is uncertain whether MPB-origin stands are suitable replacements for wildfire origin stands if left unburned. If wildfire remains infrequent in this NDU, then some amount of prescribed burning of live or MPB-killed stands should be attempted.

Patch size Since medium-sized patches (50–100 ha) are rare in the natural landscape and small patches are still naturally created by small fires, windthrow, and root disease, the emphasis should be on creating larger patches (> 100 ha) as a replacement for larger patches that would have been created by fire. Larger patches should be created by aggregating recent blocks in areas previously harvested and/or by designing new large blocks in unharvested areas. Patch size distribution should follow that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[12]

12 DeLong (1999).

Stocking and stand structure Stand density in young circumesic stands (< 40 yr) should generally be kept at total stocking levels of > 2000 sph to approximate dense natural stands. More open patchy stocking (i.e., < 1000 sph) on hygric sites is recommended. Even-aged stands over most of the landscape would approximate the natural pattern.

8 MOIST TRENCH

Location, Climate, and Vegetation

This unit occupies the Rocky Mountain Trench from approximately McBride to the southern end of McNaugton Reservoir and valleys and slopes of the Rocky Mountains east to the Continental Divide and Cariboo Mountains to their western extent.

The climate of this unit is characterized by snowy winters and warm and moist summers. This NDU is intermediate to other NDUs in terms of annual precipitation. The temperature regime varies in a gradient from valley to mountain top. Mean annual temperature of the lower elevation SBS is 3.1°C, and 4.0°C for the ICH. There are no long-term data for the ESSF. Mean annual precipitation data from long-term stations are 568 mm for the SBS, 712 mm for the ICH, and 816 mm for the ESSF. Annual snowfall often reaches 2–4 m depending on elevation.

Mature to old upland coniferous forests dominate the Moist Trench natural landscape. Hybrid white spruce and subalpine fir are the dominant climax tree species in cold air drainage areas and at elevations above about 1200 m whereas western redcedar (*Thuja plicata* Donn *ex* D. Don) and western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) are the dominant climax species on the warmer slopes. Lodgepole pine occurs on drier, poorer sites, in younger stands on most sites, and in some wetlands. Douglas-fir occurs as a long-lived seral species from valley bottom to mid-elevations, generally on mesic and drier sties. Western white pine (*Pinus monticola* Dougl. *ex* D. Don) occurs in pockets at lower elevations south of Valemount, and whitebark pine (*Pinus albicaulis* Engelm.) occurs sporadically at high elevations throughout. Paper birch and trembling aspen occur as pioneer trees in recently disturbed areas and in particular on warm slopes. Some cottonwood occurs along the floodplains of the larger rivers. Black spruce occurs in wetlands that occupy the broader valley bottoms.

Natural Disturbance Ecology

The stand replacement disturbance cycle assigned to this unit is 150 for the SBS and ICH and 300 for the ESSF. The fire cycle would have likely varied depending on site conditions. Table 3 shows the amount of forests of different age classes that would be associated with the assigned stand replacement disturbance cycle as well as patch size distribution for fire.

In the absence of stand replacement disturbance, stands are affected by damaging agents that operate in older stands, so-called matrix disturbance agents (Lewis and Lindgren 2000). The agents most commonly associated with older trees in this NDU are armillaria root disease (*Armillaria ostoyae* (Romangn.) Herink), mountain pine beetle, spruce beetle, western balsam bark beetle (*Dryocoetes confusus* (Swaine)), and tomentosus root disease. These agents alter stand species composition and horizontal and vertical structure by causing tree mortality either on their own or in combination with other damaging agents (e.g., wind, disease). Mountain pine beetle and spruce beetle may cause severe mortality at regular intervals in the SBS and ESSF portions of this NDU, leading to a shift in species composition to subalpine fir and release of suppressed trees (Lewis and Lindgren 2000).

Young natural stands in the ICH portion of this NDU may be dominated by western hemlock, lodgepole pine, spruce, aspen, paper birch, or black cottonwood depending on landscape position and disturbance history. Over time, most stands in the ICH increase in proportion of cedar with the exception of some of the driest sites, which remain hemlock and/or Douglas-fir dominated. Young stands in the ESSF portion of the NDU are generally dominated by subalpine fir, lodgepole pine, or spruce but may occasionally be dominated by aspen or paper birch, especially at lower elevations. Spruce tend to outlive subalpine fir, so they comprise the majority of the largest stems in older stands. Subalpine fir is more abundant as elevation increases due to its greater ability to survive in the severe high-elevation environment. Young natural stands in the SBS portion of this NDU are generally dominated by lodgepole pine or trembling aspen and occasionally by spruce or Douglas-fir. Over time, spruce and Douglas-fir dominate. Unpublished data (DeLong 2002) indicate snag densities (> 7.5 dbh) of 193 ± 252 sph for stands in the ICHmm.

A study by Harrison et al. (2002) indicates CWD volumes of 26–557 m^3/ha for older stands in the ICHmm and 47–753 m^3/ha for older stands in the ESSFmm. Means were 290 and 280 m^3/ha, respectively.

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has likely slowed the natural disturbance rate in this NDU. This has had the compound effect of increasing the amount of old forest in more remote areas where harvesting was not occurring (e.g., south end of McNaughton Reservoir) and reducing young forest established by fire. Increasing old forest that is the most susceptible to agents such as MPB and decreasing the amount of large patches of young forest that is least susceptible to these agents in more remote areas has likely exacerbated the current pest problems in older stands in this NDU. Planting of dense stands of very susceptible species (e.g., Douglas-fir) has likely exacerbated the spread of armillaria root disease.

Dispersed medium-sized-(40–100 ha) block harvesting and some partial cutting have been the dominant forms of harvest in this NDU. This has resulted in a reduction of larger patches in comparison to the natural landscape.

Currently, disturbance rates associated with harvesting are higher than those previously associated with wildfire, especially at higher elevation. Since this harvest is concentrated on older forest, there has likely been a decrease in the amount of older forest in this NDU.

Recommended Practices

Old forest Since forests with "old forest characteristics" were typically dispersed unevenly across the NDU (i.e., rare in some watersheds but abundant in others), old forest targets could be met over multiple watersheds rather than in each watershed. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle. Maintaining some connectivity between the old forest patches would seem warranted based on the amount of connectivity observed in the natural landscape.

Young natural forest Some proportion of areas disturbed by natural disturbance agents (e.g., wildfires, pests, wind) should be left unsalvaged to offer habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size The patch size for clearcut harvesting should follow that of wildfire Table 3 as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[13]

Silvicultural system Although not studied, the large proportion of Douglas-fir in most of the lower elevation drier ecosystems likely resulted in abundant residual structure being maintained during fire. Variable amounts of retention within clearcuts and different forms of partial cutting should be used to create a wide range of retention of residual tree cover over the landscape at lower elevations. At higher elevations, use of silvicultural systems that approximate gap disturbance seems appropriate over a significant portion of the landscape (i.e., 30%).

Stocking and stand structure Natural stands within this NDU contain a wide range of tree species, especially during the first 100 years of succession. Measures need to be developed to ensure that managed stands have a relatively similar species composition across the landscape as natural stands.

9 NORTHERN BOREAL MOUNTAINS

Location, Climate, and Vegetation

This unit occupies the valleys and mountains of the Northern Boreal Mountains Ecoregion. This NDU occurs in a broad band from approximately 57 to 60° N latitude. The unit occurs north of the Omineca NDU and west of the Boreal Plains NDU.

The climate of this unit is characterized by long, very cold, moderately snowy winters and short, moist summers. Outbreaks of cold arctic air are common throughout the winter. This unit is intermediate in precipitation but is one of the coldest NDUs. Mean annual precipitation from long-term stations is 580 mm for higher elevations and 460 mm for lower elevations, and mean annual temperature ranges from −1.5 to −2.1°C from the southern extent to northern extent.

Upland climax forests have sparse crown closure and are dominated by hybrid white spruce and/or subalpine fir. Subalpine fir dominance increases with elevation. Lodgepole pine and to a lesser extent trembling aspen dominate young stands. Black spruce occurs along with white spruce or lodgepole pine on upland sites, especially on north aspects.

Wetlands are common along the broader valleys and in flatter terrain in the mountains.

Alluvial forests of black cottonwood, often with a minor component of spruce, are found along the floodplains of the larger rivers.

13 DeLong, 1999.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit. Determining fire cycle is difficult in this NDU due to the amount of prescribed fire that has traditionally been used for management of ungulate forage. These large wildlife burns (>1000 ha) mask the natural fire history of many valleys. The provisional stand replacement disturbance cycle assigned to this unit is 180. However, fire cycle likely varied considerably based on breadth of valley, valley orientation, and slope aspect (Rogeau 2001). Table 3 shows the amount of forests of different age that would be associated with this fire cycle. Large wildfires (>1000 ha) dominated the landscape, and upland sites may be regenerated to lodgepole pine, trembling aspen (low elevations only), willows, or grasses depending on landscape position, site moisture regime, and available seed. Black spruce and white spruce regenerated the wetter areas after fire except in areas of cold air drainage where willow and scrub birch dominate. Stand ages often exceed 200 years, especially at higher elevations, and relatively large patches (>100 ha) of older forest (120–180 yr) could be found scattered across the landscape. Although patches of old forest (>140 yr) likely always occurred in the landscape at any one time period, old forest may have been rare in any particular watershed.

During stand development, increasing amounts of white and black spruce and subalpine fir will occur in stands originally dominated by lodgepole pine. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites and at higher elevations. Post-fire stands are very dense except on the wettest sites and they self-thin over time. Preliminary data indicate CWD volumes of 76 ± 39 SD m^3/ha for low-elevation forests and 80 ± 71 SD m^3/ha for high-elevation forests. No data for snags are currently available for this unit.

Forest Management Effects

Very little forest management has occurred in this NDU due to the low productivity of the forests and long distances to any major population centre. The dominant anthropogenic influence has been broadcast burning to improve ungulate range. This has resulted in more young forest and open range conditions than likely would have been present in the natural landscape. This influence is strongest in the drainages on the lee side of the Rocky Mountains.

Much of the Northern Boreal Mountains NDU is in land designations that will limit or exclude harvesting. Harvesting will generally be restricted to more productive sites in the southern portion of the NDU.

Recommended Practices

Old forest Since forests with "old forest characteristics" were typically dispersed unevenly across the NDU (i.e., rare in some watersheds but abundant in others), old forest targets could be met over multiple watersheds rather than in each watershed. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle. Based on work by Rogeau (2001), allocating more old forest to certain valleys (i.e., north–south orientated valleys) and/or slope aspects (i.e., north facing) is appropriate. Old forest may need to be recruited in areas where significant broadcast burning has occurred if a return to more natural conditions is desired. Since harvesting focusses on the most productive sites, a strategy to preserve some old forest on these sites may be necessary.

Young natural forest Young natural forest should be relatively abundant in many areas due to the amount of prescribed burning that has occurred in the past without salvage logging.

Patch size Patch sizes should be relatively natural in this NDU due to the lack of harvesting and the amount of prescribed fire, although it is unknown how natural the prescribed fire patches are.

Stocking and stand structure Stands should be relatively natural throughout most of this NDU due to the lack of effects of forest management activities.

10 OMINECA

Location, Climate, and Vegetation

This unit occupies the valleys and mountains of the Omineca Mountain Ecoregion and the northern portion of the Central Canadian Rocky Mountains Ecoregion. This NDU occurs in a broad band from approximately 55 to 57° N latitude. The unit occurs north of the Moist Interior NDU and south of the Northern Rockies NDU.

The climate of this unit is characterized by long, cold, snowy winters and short, moist summers. Outbreaks of cold arctic air are common throughout the winter. This unit is intermediate in precipitation but is one of the coldest NDUs. Mean annual precipitation ranges from 418 to 692 mm and mean annual temperature ranges from – 0.3 to 1.2°C for lower elevation forests. Climate data are not available for upper elevation forests, but the climate is thought to be similar to that of the upper elevation forests of the Boreal Foothills NDU, which has a mean annual precipitation of 780 mm and a mean annual temperature of –0.3°C.

Upland climax forests are dominated by hybrid white spruce and/or subalpine fir. Subalpine fir dominance increases with elevation. Lodgepole pine and to a lesser extent trembling aspen and paper birch dominate young stands. Black spruce occurs sporadically along with lodgepole pine on upland sites.

Wetlands are locally common along the broader valleys and in flatter terrain in the mountains.

Alluvial forests of black cottonwood, often with a minor component of spruce, are found along the floodplains of the larger rivers.

Natural Disturbance Ecology

Fire is the key stand replacement disturbance agent operating in this unit. Mountain pine beetle may be a significant stand replacement disturbance agent in localized areas. The stand replacement disturbance cycle assigned to this unit is 120 and 300, respectively, for the valley (SBSmk2, BWBSdk1, BWBSwk2) and mountain (ESSFmv3, ESSFmv4) portions. However, fire cycles likely varied considerably based on breadth of valley, valley orientation, and slope aspect (Rogeau 2001). Table 3 shows the amount of forests of different age that would be associated with these fire cycles. Large wildfires (> 1000 ha) dominated the landscape, and upland sites were generally regenerated quickly by dense lodgepole pine stands, resulting in large patches of relatively even-aged forests (Table 3). Black spruce and white spruce regenerated the wetland areas after fire. Stand ages often exceed 200 years, especially at higher elevations, and relatively large patches (>100 ha) of older forest (120–180 yr) could be found scattered across the landscape. Although patches of old forest (>140 yr) likely always occurred in the landscape at any one time period, old forest may be rare in any particular watershed.

Western balsam bark beetle and 2-year-cycle budworm cause significant within-stand mortality in spruce and subalpine fir leading stands. Western balsam bark beetle is most prevalent at higher elevations where it attacks mature subalpine fir. The 2-year-cycle budworm attacks both subalpine fir and spruce at all elevations, with highest mortality occurring in codominant or suppressed stems. Dendro-ecological analysis by Zhang and Alfaro (2002) indicate a 32-year cycle of outbreak recurrence within the Omineca NDU.

During stand development, increasing amounts of white spruce and subalpine fir will occur in stands originally dominated by lodgepole pine. This increase occurs more rapidly and these species become a more dominant portion of the canopy on wetter sites and at higher elevations. Post-fire stands are very dense except on the wettest sites and they self-thin over time. Preliminary unpublished data indicate CWD volumes of 76 ± 39 SD m^3/ha for low-elevation forests and 80 ± 71 SD m^3/ha for high-elevation forests. No data for snags are currently available for this unit.

Forest Management Effects

Fire control and harvesting pattern are likely the two factors most affecting the natural landscape pattern and processes in this NDU.

Effective fire control over the past 40–50 years has slowed the natural disturbance rate by reducing the number of large fires (Rogeau 2001). This has had the compound effect of increasing the amount of old forest in more remote areas where harvesting has not occurred and reducing young forest established by fire. These two factors may have increased mountain pine beetle attack in remote areas where harvesting rate has been low.

Some organisms appear to be heavily dependent on fire-killed forests. Hutto (1995), in a study of bird communities following stand replacement fires in the Rocky Mountains of Montana, found that Black-backed Woodpeckers were generally restricted in their habitat distribution to standing dead forests created by stand replacement fires. Certain insects and fungi appear to be either fire obligates or heavily favoured by fire (Buddle et al. 2006).

While wildfire creates disturbances of all sizes and the landscape is dominated by large disturbances, forest management has generally been directed to achieve mid-sized patches (40–100 ha) (DeLong and Tanner 1996). Larger harvest patches often occur due to management of windthrow. Dispersed harvest of mid-sized patches is both unnatural and creates fragmentation and a porous landscape for the spread of pests that attack older trees.

Recommended Practices

Old forest Since forests with "old forest characteristics" were typically dispersed unevenly across the NDU (i.e., rare in some watersheds but abundant in others), old forest targets could be met over multiple watersheds rather than in each watershed. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle. Work by Rogeau (2001) would suggest allocating more old forest to certain valleys (i.e., north–south oriented valleys) and/or slope aspects (i.e., north facing) since these areas escape fire more often than average.

Young natural forest Some proportion of natural disturbances should be left unsalvaged to provide habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size Since medium-sized patches (50–100 ha) are rare in the natural landscape and small patches are still naturally created by small fires, windthrow, and root disease, the emphasis should be on creating larger patches (> 100 ha). Larger patches should be created by aggregating recent blocks in areas previously harvested and/or by designing new large blocks in unharvested areas. Patch size distribution should emulate that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[14]

Stocking and stand structure Stand density in young circumesic stands (< 40 yr) should generally be kept at total stocking levels of > 2000 sph to approximate dense natural stands. More open patchy stocking (i.e., < 1000 sph) on hygric sites is recommended. Even-aged stands over most of the landscape would approximate the natural pattern. In areas of mixed aspen and spruce, efforts should be made to grow mixed stands similar to those that would have developed under a natural fire regime. At higher elevations or in areas with a high proportion of spruce and subalpine fir, silvicultural systems that manipulate stand structure in a manner similar to that of balsam bark beetle or 2-year-cycle budworm should be considered.

11 WET MOUNTAIN

Location, Climate, and Vegetation

This unit occupies the valleys and slopes of the Rocky Mountains west of the Continental Divide and between 54 and 56° N latitude.

The climate of this unit is continental, and is characterized by seasonal extremes of temperature: severe, very snowy winters, and cool, very wet, and short summers. This is the wettest of the NDUs in the region. Mean annual precipitation data from long-term stations are 1250 and 1537 mm, respectively, for the SBSvk and ESSFwk2. Annual snowfall often reaches 6–9 m depending on elevation. The temperature regime varies in a gradient from valley to mountain top. Mean annual temperature of the lower elevation SBSvk is 2.6°C and is 0.3°C for the higher elevation ESSFwk2.

Old upland coniferous forests dominate the Wet Mountain natural landscape. Hybrid white spruce and subalpine fir are the dominant climax tree species. Natural origin lodgepole pine is limited to some wetlands and Douglas-fir to a few dry rocky ridges. Paper birch and trembling aspen occur as pioneer trees in scattered recently disturbed areas. Some cottonwood occurs along the floodplains of the larger rivers. Black spruce occurs in wetlands that occupy some of the broader valley bottoms. Sitka alder (*Alnus viridis* ssp. *sinuata* (Regel) A. & D. Löve) occurs commonly on slopes throughout the unit on avalanche tracks and in seepage areas.

14 DeLong (1999).

Natural Disturbance Ecology

Stand replacement disturbance events occur at irregular intervals with as much as 1000 years between such events on any site. The stand replacement disturbance rate[15] for this unit is estimated to be only 0.1% [16] of the total forested area per year (DeLong 1998). The stand replacement disturbance cycle assigned to this unit is 900 based on work conducted by Hawkes et al. (1997) and DeLong (1998). Table 3 shows the NRV of forests of different age classes that would be associated with this disturbance cycle. Fire sizes are generally smaller than for other NDUs, with only 10% of the total area in patches > 1000 ha, but there is still 60% in the 100- to 1000-ha patch size (Table 3).

In the absence of stand replacement disturbance, stands are affected by damaging agents that operate in older stands, so-called matrix disturbance agents (Lewis and Lindgren 2000). The agents most commonly associated with older trees in this NDU are spruce beetle, western balsam bark beetle, tomentosus root disease, and stem decays such as Indian paint fungus (*Echinodontium tinctorium* (Ellis & Everh.) Ellis & Everh.). These agents alter stand species composition and horizontal and vertical structure by causing tree mortality either on their own or with other damaging agents (e.g., wind, disease). Spruce beetle may cause severe mortality at regular intervals, leading to a shift in species composition to subalpine fir and release of suppressed trees (Lewis and Lindgren 2000). In the absence of lodgepole pine over most of this unit, stands attain stocking slowly even after wildfire, resulting in open multi-aged early to mid-successional stands (DeLong et al. 2003). The long stand replacement disturbance rate, damaging agents causing selective mortality, and slow regeneration result in open multi-aged stands dominating the landscape.

Natural stands, of any age, generally do not exceed 1000 sph > 7.5 cm dbh, and density of the main canopy is generally < 400 sph (DeLong et al. 2003) (Table 6). Spruce tends to outlive subalpine fir in this unit, so it comprises the majority of the largest stems in older stands. Subalpine fir is more abundant as elevation increases due to its greater ability to recruit and survive in the severe high-elevation environment. Density of snags > 7.5 cm dbh is highest in young (< 70 yr) stands and generally exceeds 80 sph in most stands (Table 6). The number of snags increases with elevation such that stands in the ESSFwk2/wc3 have almost twice as many snags as equivalent stands in the SBSvk (Table 6).

Coarse woody debris volumes show little variation with stand age but decrease with elevation in correspondence to decreases in live tree volume (DeLong et al. 2003). Average CWD volume is generally 150–250 m^3/ha for stands in the SBSvk and 100–200 m^3/ha for stands in the ESSFwk2/wc3 (DeLong et al. 2003).

Arboreal lichen abundance is high in older forests, especially in the ESSFwk2/wc3. Although young stands (< 70 yr) have lower amounts of arboreal lichen, there appears to be no clear differences between mature (70–140 yr) and old (> 140 yr) stands, especially within the ESSFwk2/wc3 (DeLong et al. 2003).

Forest Management Effects

Harvesting and reforestation practices are likely the two factors most affecting the natural landscape pattern, stand composition and structure, and associated processes in this NDU.

15 All disturbance rates are for stand replacement wildfire except where noted.
16 All estimates quoted are for the period of 1911–1930 because these were deemed to more accurately reflect the true natural disturbance rate.

TABLE 6 *Mean values and standard deviation (in brackets) for selected stand characteristics in young (0–70 yr), mature (71–140 yr), and old (>140 yr) stands for the SBSvk and ESSFwk2/wc3 (n = 4 for SBSvk, n = 5 for ESSFwk2/wc3 except where noted). (Adapted from DeLong et al. 2003.)*

	SBSvk			ESSFwk2/wc3		
Stand attributes	**Young**	**Mature**	**Old**	**Young**	**Mature**	**Old**
Tree density (sph)	644[a]	811 (175)	617 (188)	342 (617)[b]	542 (177)	558 (311)
Spruce density (sph)	400[a]	475 (241)	158 (56)	1044[a]	11[a]	133 (103)
Subalpine fir density (sph)	244[a]	333 (136)	455 (175)	33.3 (15.7)[b]	540 (181)	424 (344)
Main canopy density (sph)	244[a]	319 (72)	128 (58)	173 (332)[b]	182 (112)	158 (64)
Snags < 15 cm dbh (sph)	69 (80)	56 (63)	25 (29)	67 (97)	19 (6)	36 (23)
Snags 15–25 cm dbh (sph)	86 (52)	14 (14)	17 (11)	222 (177)	64 (23)	52 (23)
Snags > 25 cm dbh (sph)	103 (83)	25 (32)	39 (29)	253 (129)	158 (150)	62 (58)
Snag density (sph)	258 (138)	94 (91)	80 (46)	440 (428)	220 (176)	122 (73)
Snag basal area (m^2/ha)	10.6 (16.2)	7.4 (9.6)	12.3 (1.1)	25.8 (19.9)	17.7 (14.8)	8.0 (6.7)
Mean dbh main canopy (cm)	24.2[a]	32.1 (8.2)	49.5 (6.3)	22.5 (4.1)	27.5 (7.9)	38.8 (12.6)
Mean dbh spruce (cm)	15.7[a]	27.9 (9.3)	42.9 (8.9)	18.9[a]	19.7[a]	41.6 (4.1)
Mean dbh subalpine fir (cm)	21.7[a]	17.0 (7.4)	21.6 (3.5)	16.7 (4.0)[b]	20.7 (4.6)	18.3 (3.3)
CWD volume < 15 cm diam. (m^3/ha)	16.4 (5.7)	13.3 (22.5)	9.0 (3.6)	9.7 (9.5)	4.7 (3.0)	8.1 (5.8)
CWD volume 15–25 cm diam. (m^3/ha)	41.0 (19.6)	58.7 (70.6)	58.5 (6.9)	29.8 (16.3)	31.6 (22.6)	39.2 (26.0)
CWD volume > 25 cm diam. (m^3/ha)	132.4 (56.8)	175.7 (99.0)	183.9 (54.2)	72.9 (29.6)	117.8 (55.9)	157.6 (178.5)
Total CWD volume (m^3/ha)	189.8 (67.5)	264.9 (65.9)	251.3 (50.1)	111.6 (24.2)	154.2 (48.6)	204.9 (203.6)

Note: sph = stems per hectare.
a Only one plot had trees with > 7.5 cm dbh.
b Based on four plots because three of the plots trees over 7.5 cm dbh were from the pre-disturbance cohort.

Clearcut harvesting has been extensive in portions of this NDU, resulting in more area in early seral stands and less area in older forest than would have existed in the natural landscape. Lodgepole pine has been planted in some areas within this NDU on sites where there is no present evidence of it having occurred. Current practices favouring the planting of spruce over subalpine fir at higher elevations will likely lead to stands with a higher proportion of spruce in managed stands as compared to natural stands. Current reforestation standards for stocking will result in stands being more densely stocked and more even-aged than natural stands. The potential impacts of the conversion of a landscape dominated by older more open stands to a landscape with a high proportion of denser younger even-aged stands are uncertain. Lewis and Lindgren (2000) hypothesize that a transition to more homogenous stands could result in significant pest outbreaks, specifically of white pine weevil (*Pissodes strobi*) and tomentosus root rot. Having more closed stands could also reduce long-term stand productivity. Kimmins and Hawkes (1978) hypothesized that the abundant understorey vegetation, which is both a cause and effect of open stand structure, contributes to nutrient conservation and rapid turnover of nutrients, enabling productive stands to develop on poor soils. The implications for wildlife are uncertain but significant alteration of stand structure and amount of gap area will likely affect some species. There is documented use of forest gaps by grizzly bears for feeding and bedding.

Recommended Practices

Old forest Since forests with "old forest characteristics" dominated the landscape in this NDU, old forest reserves should be well distributed throughout all watersheds. A high degree of connectivity between these old forest patches should be planned since there was always a high degree of connectivity of old forest in the natural landscape. Since differences between mature (80–140 yr) and old (>140 yr) forests appear to be limited based on available data, some flexibility in the current age criterion for "old-growth forest" should be considered. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of areas disturbed by natural disturbance agents (e.g., wildfires, pests, wind) should be left unsalvaged to offer habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size The patch size for clearcut harvesting should follow that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[17]

Silvicultural system Some form of partial cutting that approximates the effects of spruce beetle attack would seem appropriate to maintain the type of stand structure most common in the natural landscape. Some balance between this system and clearcut with reserves to approximate wildfire pattern is warranted.

Stocking and stand structure Appropriate measures need to be developed to achieve open, patchy, multi-storied stands over most of the landscape.

17 DeLong (1999).

Location, Climate, and Vegetation

This unit occupies the Rocky Mountain Trench from approximately Purden Lake to McBride, the valleys and slopes of the Rocky Mountains east to the Continental Divide, and the valleys and slopes of the Cariboo Mountains to their western extent.

Cool, very snowy winters, and warm and very wet summers characterize the climate of this unit. This NDU is second to the Wet Mountain NDU in terms of annual precipitation. The temperature regime varies in a gradient from valley to mountain top. Mean annual temperature of the lower elevation ICH is 3.3–4.8°C and −0.1 to −0.3°C for the higher elevation ESSF. Mean annual precipitation data from long-term stations are 840 mm for the ICH and 1044–1538 mm for the ESSF. Annual snowfall often reaches 4–8 m depending on elevation.

Old upland coniferous forests dominate the Wet Trench natural landscape. Hybrid white spruce and subalpine fir are the dominant climax tree species in cold air drainage areas and at elevations above about 1200 m whereas western redcedar and western hemlock are the dominant climax species on the warmer slopes. Lodgepole pine is limited to some wetlands and the occasional rocky ridge, and dispersed older Douglas-fir are found on drier sites. Paper birch and aspen occur as pioneer trees in scattered recently disturbed areas. Some cottonwood occurs along the floodplains of the larger rivers. Black spruce occurs in wetlands that occupy the broader valley bottoms. Sitka alder occurs commonly on slopes at higher elevations throughout the unit, on avalanche tracks, and in seepage areas.

Natural Disturbance Ecology

Stand replacement disturbance events occur at irregular intervals, with time between stand replacement disturbances estimated to exceed 1000 years on some sites. The stand replacement disturbance cycle assigned to this unit is 600 for the ICH and 800 for the ESSF. The fire cycle would have likely varied considerably depending on site conditions. It is felt that some toe slope sites in the ICH may not have had a stand replacement fire for 1000 years or more. Western hemlock looper (*Lambdina fiscellaria* ssp. *lugubrosa* (Hulst)) can cause significant tree mortality leading to stand replacement. Outbreaks covering tens of thousands of hectares have been recorded (Parfett et al. 1995; S. Taylor, unpublished data). Table 3 shows the amount of forests of different age classes that would be associated with the assigned stand replacement disturbance cycle. Patch size distribution of fire has not been determined but is thought to be similar to that of the Wet Mountain NDU (Table 3).

In the absence of stand replacement disturbance, stands are affected by damaging agents that operate in older stands, so-called matrix disturbance agents (Lewis and Lindgren 2000). The agents most commonly associated with older trees in this NDU are spruce beetle, western balsam bark beetle, tomentosus root disease, and stem decays such as Indian paint fungus. The 2-year-cycle budworm attacks both subalpine fir and spruce at higher elevations, with highest mortality occurring in codominant or suppressed stems (Zhang and Alfaro 2002). These agents alter stand species composition and horizontal and vertical structure by causing tree mortality either on their own or in combination with other damaging agents (e.g., wind).

Young natural stands in the ICH portion of the NDU may be dominated by western hemlock, spruce, aspen, paper birch or black cottonwood depending on landscape position and disturbance history, and are generally dense to very dense (> 5000 sph). Over time, most stands increase in proportion of cedar with the exception of some of the driest sites, which remain hemlock dominated. Young stands in the ESSF portion of the NDU are generally dominated by spruce or subalpine fir and occasionally by lodgepole pine or aspen, especially at lower elevations. Spruce tends to outlive subalpine fir so it comprises most of the largest stems in older stands. Subalpine fir is more abundant as elevation increases due to its greater ability to regenerate and survive in the severe high-elevation environment. Based on a study by Harrison et al. (2002), snag density (> 7.5 dbh) of older stands is 145 ± 97 SD sph for the ICHwk3 and 128 ± 74 SD sph for the ESSFwk1. A range of 28–65 dead sph was reported by Stevenson et al. (2006) for older stands in the ICHwk3 and ICHvk.

The study by Harrison et al. (2002) indicates CWD volumes in older stands range from 144 to 658 m^3/ha for the ICHwk3 and from 60 to 425 m^3/ha for the ESSFwk1. Means were 255 and 243 m^3/ha, respectively. Stevenson et al. (2006) report CWD volumes of 220–387 m^3/ha for older stands in the ICHwk3 and ICHvk.

Arboreal lichen abundance is high in older forests in the ESSF. Harrison et al. (2002) found greater numbers of trees with high abundance of arboreal lichen in stands > 200 years old versus stands < 200 years old.

The very oldest forests within the ICH portion of this unit support some globally rare arboreal lichen assemblages (Goward and Spribille 2005). Work done by Goward (1994) indicates that the oldest (> 300 yr) forests support more species and a greater abundance of these species.

Forest Management Effects

Harvesting rate and reforestation practices are likely the two factors most affecting the natural landscape pattern, stand composition and structure, and associated processes in this NDU.

Clearcut harvesting has been extensive in portions of this NDU, resulting in more area in early seral stands and less area in older forest than would have existed in the natural landscape.

Lodgepole pine has been planted in some areas within this NDU on sites where there is no present evidence of it having occurred. In the ICH portion of this NDU, current practices of favouring spruce over hemlock or cedar will lead to stands with a higher proportion of spruce in managed stands compared to natural stands. In the ESSF portion, the same is true for spruce versus subalpine fir (i.e., current practices will lead to stands with a higher proportion of spruce). Heavy attacks of spruce plantations by white pine weevil have been recorded in stands previously dominated by cedar and hemlock.

Recommended Practices

Old forest Since forests with "old forest characteristics" dominated the landscape in this NDU, old forest reserves should be well distributed throughout all watersheds. A high degree of connectivity between these old forest patches should also be managed since there was always a high degree of connectivity of old forest in the natural landscape. Since the oldest forests in this NDU have unique values (e.g., rare arboreal lichen communities), efforts should be made to capture as much of the oldest forest in reserves as possible. Intensive management of these very productive forests in areas already impacted by forest harvest can reduce the harvesting pressure on the remaining old forest since the current harvest level can be attained from a smaller area. Table 3 contains estimates of the NRV of the time since last stand replacement disturbance distribution based on the estimated fire cycle.

Young natural forest Some proportion of areas disturbed by natural disturbance agents (e.g., wildfires, pests, wind) should be left unsalvaged to offer habitat (e.g., burned snags) that cannot be provided by young managed stands.

Patch size The patch size for clearcut harvesting should follow that of wildfire (Table 3) as closely as possible given social, logistic, or demonstrated ecological constraints. Design of blocks should follow guidance provided in DeLong.[18]

Silvicultural system Some form of partial cutting that approximates the effects of hemlock looper attack would be appropriate in the ICH to maintain the type of stand structure associated with this disturbance agent. At higher elevations, use of silvicultural systems that approximate gap disturbance would be appropriate over a significant portion of the landscape (i.e., > 50%).

Stocking and stand structure Measures need to be developed to ensure that managed stands have a relatively similar species composition across the landscape as natural stands.

13 IMPLEMENTATION OF GUIDANCE

To implement the recommended practices discussed in previous sections, it is necessary to determine tradeoffs with respect to meeting resource targets (e.g., timber, scenic, wildlife) and set objectives that can be reasonably achieved. To date, landscape level objectives have been developed and are currently being implemented by joint government industry groups in two large areas (Figure 2). The guidance and policy developed for these areas is briefly described here.

The first area is for the Prince George Timber Supply Area (PGTSA) where in 2002 the Landscape Objectives Working Group (LOWG) was formed to develop landscape level and stand level guidance for management of biodiversity within the PGTSA. Its first task was to develop natural disturbance-based management guidance and policy relating to three objectives: old forest, interior old forest, and patch size.

A timber supply analysis was conducted to determine the implication to long-term timber supply of implementing different targets for old forest based on the NRV limits for the NDSs (Table 3). In total, 13 scenarios were run, including the base case at the time which included an uplift for managing the mountain pine beetle outbreak. Table 7 shows the assumptions for the base case (Scenario 1) plus a scenario that attempted to meet the minimum

18 DeLong (1999).

FIGURE 2 *Two areas where implementation of guidance and policy based on Natural Disturbance Unit approach has occurred.*

TABLE 7 *Area of timber harvesting and non-contributing land bases, estimated percentage of total forested area in forests >140 years old for natural forests, and targets for managed forests under three different scenarios for Natural Disturbance Sub-units in the timber supply modelling exercise*

Natural Disturbance Sub-unit	Timber harvesting land base (ha)	Non-contributing land base (ha)	NRV[a] for forest >140 years (% of total forested area)	Scenario target >140 years (% of total forested area)		
				1[b]	2	3
McGregor Plateau	217 807	78 325	43–61	11–34	43	26
Moist Interior–Mountain	135 313	58 720	41–61	14–42	41	29
Moist Interior–Plateau	1 543 574	604 199	17–33	11–34	12 or 17	12 or 17
Northern Boreal Mountains	81 401	121 849	37–60	14–42	37	37
Omineca–Mountain	300 123	250 027	58–69	14–42	58	58
Omineca–Valley	593 672	186 942	23–40	11–34	23	16
Wet Mountain	552 936	221 903	84–89	15–54	84	50
Wet Trench–Mountain	97 997	212 637	80–88	19–54	80	48
Wet Trench–Valley	292 046	158 657	76–84	17–51	76	53

a NRV = natural range of variability.

b Target varies by landscape unit depending on emphasis (i.e., low, intermediate, or high biodiversity emphasis). See B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks (1995, 1999) for more details.

estimate of NRV (Scenario 2), and a final scenario (Scenario 3) chosen to be presented to the decision makers. The reduction in the long-term sustained allowable annual cut for Scenario 2 was 18% and 1.4% for Scenario 3. The decision maker adopted Scenario 3, which was used to set old forest requirements within the PGTSA (B.C. Ministry of Sustainable Resource Management 2004a). Further details can be found in DeLong (2007).

The reduction of old forest that is unaffected by edge or "interior old forest" is often a consequence of forest fragmentation from dispersed harvesting (DeLong and Tanner 1996).The LOWG in the PGTSA determined the amount and patch size of interior old forest to establish some reasonable objectives for its management. Interior old forest was considered to be any forest > 140 years old that was > 200 m away from an abrupt forest edge. This is a liberal estimate of the edge effects based on data for northern British Columbia (Burton 2001, 2002). An abrupt forest edge was considered to be lodgepole pine or deciduous dominated stands that were < 61 years old, stands dominated by other species that were < 81 years old, primary access roads, pipelines, railways, and hydro transmission corridors. Currently, the legal requirement for interior old forest in the PGTSA is 10, 25, or 40% of total amount of old forest depending on history of past fragmentation and estimated natural degree of connectedness of old forest for the NDS. Further details can be found in the PGTSA Landscape Objective Working Group Background Report (B.C. Ministry of Sustainable Resource Management 2004b).

Targets for patch size of young forest were also developed using the estimated patch size distributions (Table 3). The approach with this objective was to ensure that management plans would result in the future patch size of the managed forest being closer to that of the natural. Whether these patch sizes are retained over time in the landscape will be influenced by the combination of natural and unforeseen management intervention (e.g., managing pest outbreaks).

As previously stated, the mountain pine beetle outbreak has made it more difficult to achieve the objectives due to the vast amount of forest impacted, especially in areas like the Moist Interior Plateau NDS. However, since some of the attributes (e.g., large snags, some large live trees, high levels of CWD) remain on the mountain pine beetle impacted sites, the approach is to allow these forests to contribute to old forest until they can be replaced by forests with higher old-growth quality.

The second area where guidance based on this document was implemented is the Fort St. John Code Pilot, developed in 2001 using a portion of the *Forest Practices Code of B.C. Act*, which allowed pilot projects to be established to experiment with ways to improve the regulatory framework for forest practices. The Sustainable Forest Management Plan (SFMP) developed as part of the pilot sets targets old forest and patch size of young forest using the NDS NRV ranges in Table 3.[19]

The old forest targets are set to the low end of the NRV for high forest intensity zones and to the mean to high end of the NRV for low and moderate forest intensity zones. Since much of the forested area is not in the timber harvesting land base, the consequences of managing to these targets was not felt to be overly restrictive to meeting timber supply objectives, and no modelling was conducted to determine the impact of meeting the targets.

19 See pp. 69–71, http://fsjpilotproject.com/documents/FSJ%20Pilot%20Project%20Draft%20SFM%20Plan%20(Part%201%20-%20Document).pdf

For the Fort St. John Code Pilot, patch size targets for young forest are set as ranges around the numbers indicated in Table 3 to provide flexibility in meeting the target. The objective for patch size is to be within the range specified for the different patch sizes in the SFMP in a certain proportion of the reporting units within the time frame of the SFMP. The SFMP also states targets for patch size of mature forest to achieve the same purpose as the interior old forest targets specified for the PGTSA above.

The stand level recommendations stated for each NDS are meant to stimulate ideas for forest managers and practitioners for the development of stand level practices that will result in stand composition and structures that were common in the natural landscape. A myriad of factors, including relative tree species growth rates, First Nations value, wildlife value, and suitability for future climate, must be considered when developing stand level prescriptions. However, the cost of straying too far from what would be suggested by examining naturally reforested areas is becoming clear. The recent outbreak of Dothistroma needle blight on lodgepole pine in northwestern B.C. has demonstrated the potential implications of relying heavily on tree species not naturally common in the landscape (Woods 2003).

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