Ecological variability of high elevation forests in central British Columbia¹

by Craig DeLong² and Del Meidinger³

High-elevation, late-successional forests over much of British Columbia are dominated by Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.). Throughout the range of these forests, however, there is a wide variation in natural disturbance and successional dynamics as influenced by diverse climate and topography. We divided these high elevation forests into four groups arranged along a regional climatic gradient that affects forest composition, structure and disturbance regime. For each, we describe the climate, topography, major vegetation, and natural disturbance dynamics. We suggest that management practices reflect the ecological variability demonstrated for these high elevation forests.

Keywords: high elevation forests, ecological variability, natural disturbance dynamics, vegetation, Engelmann spruce, subalpine fir, British Columbia, climate, topography

Les forêts de hautes altitudes et de fin de succession pour l'ensemble de la Colombie-Britannique sont dominées par l'épinette d'Engelmann (*Picea engelmannii* Parry ex. Engelm.) et par le sapin subalpin (*Abies lasiocarpa* (Hook.) Nutt.). Au sein de la distribution de ces forêts, il existe cependant une grande variation dans les dynamiques de perturbation naturelle et de succession découlant des climats variés et de la topographie. Nous avons divisé ces forêts de haute altitude en quatre groupes selon un gradient climatique régional qui affecte la composition forestière, la structure et le régime de perturbation. Pour chacun de ces groupes, nous décrivons le climat, la topographie, les principaux végétaux et la dynamique des perturbations naturelles. Nous suggérons que les pratiques d'aménagement reflètent la variabilité écologique démontrée pour ces forêts de haute altitude.

Mots-clés : forêts de haute altitude, variabilité écologique, dynamique des perturbations naturelles, végétation, épinette d'Engelmann, sapin subalpin, Colombie-Britannique, climat, topographie

Introduction

Late-successional forests dominated by Engelmann spruce (*Picea engelmannii* Parry ex. Engelm.) and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) are widespread at high elevation over a large portion of British Columbia. Classified by the Biogeoclimatic Ecosystem Classification system (Pojar *et al.* 1987) as belonging in the Engelmann Spruce – Subalpine Fir (ESSF) Zone (Meidinger and Pojar 1991), they cover approximately 14.2 million ha of land in B.C. This compares to the other high elevation forest zones, the Spruce – Willow – Birch Zone and the Mountain Hemlock Zone, which cover 3.5 and 7.2 million ha, respectively.

Although the tree species composition and structure of old forests is similar and the climate is relatively cold over the geographic extent of the ESSF zone, there is a wide range in the climatic regime that results in differences in regeneration, natural disturbance dynamics, successional and vegetation patterns. This range in climate is reflected in the 17 forested biogeoclimatic subzones currently described for the zone in B.C. (Coupé *et al.* 1991, Steen and Coupé 1997, Braumandl and Eng 2002). In this paper, we illustrate the climatic variation in the zone and its influence on forest dynamics, and management decision-making.

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To simplify the climatic variation, we have divided the ESSF forested subzones into four groups (Very Dry, Dry, Moist and Wet) based on a regional climatic gradient that affects forest composition, structure and disturbance regime. The geographical distribution of these four groups is illustrated in Fig. 1 and the assignment of biogeoclimatic units to the groups is shown in Table 1. We compare the climate, general topography, major vegetation, and natural disturbance dynamics between these four groups. We also discuss how the differences lend themselves to different forest management practices.

Climate and Topography

The largest differences in climate between the ESSF groups are related to precipitation. Mean annual precipitation (MAP) ranges from 524–1712 mm, with the group averages increasing from the very dry group to the wet group (Table 2). Although there is considerable variation in MAP within some

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Fig. 1. Geographical distribution of four ESSF climate groups.

Table 1. Assignment of biogeoclimatic subzones to the ESSF climate groups

Very Dry	Dry	Moist	Wet
ESSFxc*	ESSFdm	ESSFmw	ESSFwm
ESSFv	ESSFdk	ESSFmm	ESSFwk
	ESSFdc	ESSFmk	ESSFwc
	ESSFdv	ESSFmc	ESSFvw
		ESSFmv	ESSFvc
			ESSFvv

*Subzone codes of two letters; first letter: x = very dry, d = dry, m = moist, w = wet, v = very wet; second letter: w = warm, m = mild, k = cool, c = cold, v = very cold (see Meidinger and Pojar 1991 for more detail).

Table 2. Mean and range in mean annual precipitation (MAP) and mean seasonal precipitation (MSP) for ESSF groups

ESSF group	Climatic variable	
	MAP (mm)	MSP (mm)*
Very Dry	721 (524–918)	236
Dry	860 (677–1207)	303
Moist	1005 (625–1995)	300 (257–398)
Wet	1355 (1044–1712)	457 (426–516)

*mean seasonal precipitation is for the time period of May 1 to September 31

of the groups, subzones within a group display similar vegetation on average sites as well as disturbance and successional patterns across the landscape. This is likely due to climatic factors other than MAP that result in similar soil moisture regime within the ESSF group.

The Very Dry ESSF group occurs in more gently sloping topography than the other ESSF groups (Table 3). The gentler relief of the Very Dry ESSF makes vegetation-damaging frosts a common feature. For example, there were up to five killing frosts (air temperature $< -4^{\circ}\text{C}$) recorded in the month of July within one year in the Very Dry ESSF (unpublished data, B. Sagar). In contrast, data from a research trial in the Moist ESSF recorded no killing frosts over eight measurement years, including the year of the aforementioned study, in the month of July (Sagar *et al.* 2001).

Table 3. Proportional area of ESSF group in different slope gradient classes

ESSF group	Slope gradient (%)			
	0–10	10–20	20–40	> 40
Very Dry	37	32	23	8
Dry	16	25	40	19
Moist	24	30	36	10
Wet	13	25	44	18

In the Moist and Wet ESSF, the higher proportion of steep slopes along with higher snow packs increases the probability of avalanches and snow creep.

Climate plays a key role in limiting the success of tree regeneration establishment. Low air and soil temperature are common environmental constraints to regeneration throughout the ESSF but others such as high soil moisture, snow cover duration, and growing season frost are more prevalent in certain portions of the ESSF. Climate and microclimate studies associated with silviculture systems trials such as Stathers *et al.* (2001) and Sagar *et al.* (2001) are establishing some of the climatic limiting factors for regeneration but most studies are limited to the Wet ESSF.

Vegetation

Late-successional forests throughout the ESSF zone are dominated by Engelmann spruce and subalpine fir. Lodgepole pine is common in early- to mid-successional stands, especially in the Very Dry to Moist ESSF groups. Whitebark pine (*Pinus albicaulis* Engelm.) and subalpine larch (*Larix lyallii* Parl.) are locally common in some parts of the zone. Mountain hemlock (*Tsuga mertensiana* (Bong.) Carrière) can be abundant in the Wet ESSF group, particularly in areas adjacent to the Mountain Hemlock zone.

Common understory vegetation throughout the forested ESSF, on mesic sites (i.e., sites of average moisture), include the shrubs white-flowered rhododendron (*Rhododendron alb-*

iflorum Hook.) and black huckleberry (*Vaccinium membranaceum* Dougl. ex Hook.); the herbs heart-leaved arnica (*Arnica cordifolia* Hook.) and Sitka valerian (*Valeriana sitchensis* Bong.); and bryophytes *Barbilophozia lycopodioides* (Wallr.) Loeske, *Brachythecium* spp. and *Dicranum* spp.

In the Very Dry and Dry ESSF, grouseberry (*Vaccinium scoparium* Leib.) is a consistent component of the understory. Arctic lupine (*Lupinus arcticus* S. Wats.) and subalpine daisy (*Erigeron peregrinus* (Banks ex Pursh) Greene) are characteristic of mesic sites in the Very Dry ESSF.

The shrubs black gooseberry (*Ribes lacustre* (Pers.) Poir.) and western mountain-ash (*Sorbus scopulina* Greene) and herbs bunchberry (*Cornus canadensis* L.) and stiff clubmoss (*Lycopodium annotinum* L.) are common on most sites in the Moist and Wet ESSF but are only occasionally present on mesic sites in the Very Dry and Dry ESSF. Twinflower (*Linnaea borealis* L.) is indicative of mesic sites in the Moist ESSF while oak-fern (*Gymnocarpium dryopteris* (L.) Newman) and three-leaved foamflower (*Tiarella trifoliata* L.) are indicative of mesic sites in the Wet ESSF.

Natural Disturbance

Historically, fire played a key role in shaping the temporal and spatial pattern of forests in the Very Dry and Dry ESSF forests, whereas it played an increasingly reduced role in the Moist to Wet ESSF forests. In the Very Dry ESSF forests there is evidence of some stand-maintaining fire events, where a significant proportion of the lodgepole pine canopy survives the fire resulting in a multi-aged lodgepole pine forest. However, in both the Very Dry and Dry ESSF groups, stand replacement fires, which result in an even-aged lodgepole pine forest, predominate.

Due to the infrequency of fire in the Wet ESSF, lodgepole pine is generally found only on the driest sites or not at all. Consequently, following a fire event, Engelmann spruce and subalpine fir are the only species present to provide seed to the burned area. Both these species recruit poorly after fire relative to lodgepole pine. The poorer recruiting ability of these species, combined with a short growing season and intense competition from shrub and herb vegetation results in slow sapling recruitment in young stands following fire. In the absence of stand-replacement fire, stands in the Wet ESSF are substantially affected by disturbance agents that operate in older stands, so called matrix disturbance agents (Lewis and Lindgren 2000). The disturbance agents most commonly associated with these forests are spruce beetle (*Dendroctonus rufipennis* Kirby), western balsam bark beetle (*Dryocoetes confusus* Swaine), two-year cycle budworm (*Choristoneura biennis* Freeman), 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 in combination with other disturbance agents (e.g., wind). Spruce beetle may cause severe mortality at regular intervals leading to a shift in species composition from Engelmann spruce to subalpine fir and release of suppressed trees of both species (Lewis and Lindgren 2000).

Young even-aged forests originating from stand replacement fire and older multi-cohort stands with significant mortality due to matrix disturbance agents are both common in the Moist ESSF group.

The natural disturbance dynamics of the ESSF zone is relatively unknown. In particular we know very little about the

action and interaction of the various disturbance agents at different spatial scales and how this changes with climatic regime. Research has been limited to landscape pattern analysis of fire (Vasbinder 2001) and detailed dendrochronological analysis of stand level disturbance (Parish *et al.* 1999, Antos and Parish 2002, Parish and Antos 2002) in the Wet ESSF and a landscape level dendrochronological analysis of two-year cycle budworm (Zhang and Alfaro 2002) in the Moist ESSF.

Forest Management

Small to medium sized (< 60 ha) clearcuts followed by prompt regeneration with lodgepole pine and/or Engelmann spruce is the dominant silviculture system currently applied in most of the ESSF zone. A recently proposed model for forest management assumes that biodiversity can be maintained by designing forest harvesting to approximate the landscape and stand conditions created by natural disturbance (Hunter 1993, DeLong and Tanner 1996, DeLong and Kessler 2000). This paradigm would suggest a silviculture system that emulates stand-replacement wildfire would predominate in the Very Dry and Dry ESSF. This paradigm would also suggest the use of silvicultural systems that emulate gap dynamics should increase proportionally from the Dry to the Wet ESSF along with the increase in natural tree mortality due to gap forming processes such as windthrow, balsam bark beetle, and two-year cycle budworm. Currently, these processes continue to persist in the relatively abundant old forest in the Wet ESSF. A recent survey by DeLong (unpublished data) indicated that at least 50% of the forests in the Wet ESSF are over 140 years old.

Recently established silvicultural systems trials at Sicomous Creek near Kamloops (Hollstedt and Vyse 1997), in the Cariboo Mountains near Williams Lake (Sutherland *et al.* 1992), and at Lucille Mountain near McBride (Jull and Stevenson 2001) all occur within the Moist and Wet ESSF group and are intended to compare gap-based silvicultural systems to the traditional clearcut method. These trials will provide critical information in order to assess the ability of silviculture systems to maintain function in these stands. However, maintaining abundant natural old forest is likely critical for maintaining the range of gap process functions and for providing natural disturbance baseline information to increase our understanding of these forests.

Forest management within the ESSF zone is challenging just due to the relative harshness of the climate. Making it even more challenging is the considerable ecological variability we have demonstrated, which restricts the application of new knowledge to limited portions of the zone. The ESSF groups that we describe may be a useful tool to focus research to fill obvious gaps.

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