Extension Note

BC Journal of Ecosystems and Management

Range of natural variability: Applying the concept to forest management in central British Columbia

Carmen Wong[1] and Kristi Iverson[2]

Abstract

The range of natural variability (RNV) is a concept relevant to maintaining biodiversity and resilience in managed forests. It is, however, a challenging concept both to describe and apply. Here, we refine the definition of RNV. We also discuss information and data sources required and the appropriate use of spatial and temporal scales. A new term, the apparent range of variability (ARV), is suggested to convey the dependency of estimates of the RNV on the temporal and spatial extent of available data sources. We offer a process for developing an RNV definition, applying it operationally, and integrating desired future conditions with social and economic values. We illustrate the challenges in defining and implementing the RNV concept with an example of the interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) forests in Lignum Ltd.'s Innovative Forest Practices Agreement area in central British Columbia.

KEYWORDS: *apparent range of variability, ecosystem management, fire regime, forest management, historic variation, interior Douglas-fir, range of natural variability.*

Contact Information

1 Forest Ecologist, Forsite Consultants Ltd., 330–42nd Street SW, PO Box 2079, Salmon Arm, BC V1E 4R1.
E-mail: cmwong@alumni.sfu.ca

2 Iverson and MacKenzie Biological Consulting Ltd., PO Box 511, Lac la Hache, BC V0K 1T0.
E-mail: kiverson@bcinternet.net

Volume 4, Number 1, 2004
http://www.forrex.org/jem/2004/vol4/no1/art3.pdf

Introduction

In search of strategies to maintain biodiversity, researchers and managers have emphasized the concept and application of the range of "natural" or "historical" variability in ecosystem structure and dynamics (e.g., Swanson *et al.* 1994; Fulé *et al.* 1997; Cissel *et al.* 1999; Landres *et al.* 1999; Long and Smith 2000). The concept of the range of natural variability (RNV) is now being widely applied in forest management situations, often to maintain and restore ecological integrity and key processes (Cissel *et al.* 1999; Landres *et al.* 1999; Moore *et al.* 1999). The RNV is not usually a management goal unto itself; instead it is integrated with social and economic constraints to set a desired future condition. In British Columbia, the concept of RNV is inherent in the *Biodiversity Guidebook* of the earlier Forest Practices Code, but is only described for broad classes of ecosystems.

Applying the concept of RNV is challenging partly due to unclear definitions and methods. The meaning of "natural" can be debated, and there is no simple method to measure and apply the RNV. In this paper, we explore the RNV and outline how this concept can be applied to management in the Interior Douglas-fir (IDF) biogeoclimatic zone under Lignum Ltd.'s Innovative Forest Practices Agreement (IFPA) in central British Columbia.

In this paper, we:

1. outline the rationale for using the RNV concept to guide forest management;
2. define RNV and methods used to estimate it;
3. suggest a process to apply this concept to forest management in the IDF; and
4. describe some of the challenges and limitations in using the RNV concept.

Rationale for Using Range of Natural Variability as a Guide in Forest Management

Given that we cannot know how human-induced changes to ecosystems affect all species, approximating the range of natural variability in ecosystem processes and structure provides the best available model for maintaining conditions to which most species are adapted (Landres *et al.* 1999; Lertzman *et al.* 1999). However, past management of ecosystems has tried to simplify ecological systems by reducing variability and eliminating natural disturbances (Holling and Meffe 1996). Ironically, this approach has reduced the resilience of many forests to disturbances; for example, fire exclusion in many fire-prone ecosystems is thought to cause an extensive accumulation of fuels and a shift from predominantly low-severity fires to the potential for high-severity, stand-replacing fires (Morgan *et al.* 1994; Holling and Meffe 1996; Moore *et al.* 1999). Maintaining the range of natural variability in a system should maintain its long-term health and reduce the risk of deleterious effects such as reduced biological diversity or productivity (Morgan *et al.* 1994; Holling and Meffe 1996; Quigley and Arbelbide 1997). Further, ecosystems managed within their RNV may be less likely to respond catastrophically to climate change than are simplified ecosystems (Swanson *et al.* 1994).

Applying the concept of range of natural variability is challenging partly due to unclear definitions and methods.

Defining the Range of Natural Variability

All of the definitions of "historical" or "natural" variability or "range of natural variability" include the elements of variability, ecological processes and structures, and a time period relatively less affected by Europeans or post-industrial humans (e.g., Morgan *et al.* 1994; Fulé *et al.* 1997; Landres *et al.* 1999; Swetnam *et al.* 1999; Dorner 2002).

In this paper, we define RNV as: *the temporal and spatial distribution of ecological processes and structures prior to European settlement of North America* (see Figure 1).

Temporal and spatial patterns in ecological processes and forest structure are critical to understanding and applying RNV. The temporal and spatial scales at which research and management are conducted must match the scales of processes that created those patterns; if not, conclusions may be artifacts of scale (Allen and Hoekstra 1991; Swetnam *et al.* 1999). These scales depend on the nature of the disturbance regimes, their climatic and topographic drivers, and the lifespan of organisms.

Temporal scale refers to both the length and the dates of the reference time period. This period should be long enough to represent a range of variability, but not so long that significant changes such as large climatic shifts have taken place (Morgan *et al.* 1994). For example, using RNV defined over the last millennium would have

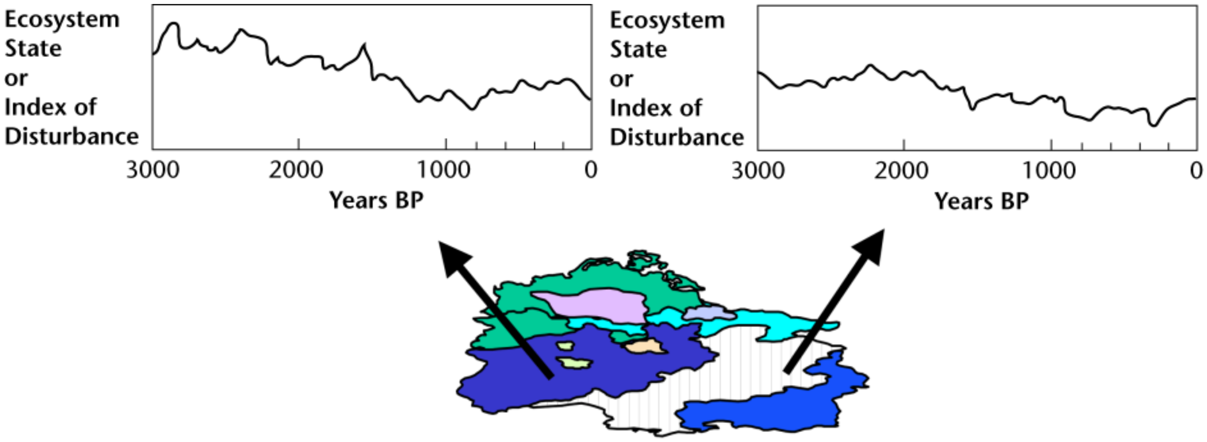

FIGURE 1. Thematic diagram of the range of natural variability showing the variability in ecosystem state (e.g., stand density, patch size) or disturbance index (e.g., fire return interval) over time and different parts of the landscape. Modified with permission from Lertzman *et al.* (1999).

to consider the influence of at least three climatic periods (Miller and Woolfenden 1999). The dates chosen should also base the RNV on a period when industrial human influences were minimal, which in most cases means examining forest dynamics before European settlement. It may be appropriate to choose different time frames for different processes or attributes depending on the data available, the reliability of those data, and the way in which the process or attribute varies with climate change or human disturbance.

Historical records present on the landscape "fade" over time. The record becomes less reliable and complete further back in time (e.g., the IDF has typically fewer older fire-scarred trees in a data set than younger ones). Thus, the analysis period should also be a function of that which is best replicated and most reliable, recognizing that the historical record of any given area may be one possible outcome out of a few from a stochastic regime of natural disturbances (Lertzman *et al.* 1998).

The spatial scale of ecological processes can range from smaller than a tree to several watersheds. The spatial scale should be large enough to capture the variability in ecological processes and structures of interest. This likely requires encompassing the area being managed and adjacent areas of similar ecological nature (Swetnam *et al.* 1999; Wimberly *et al.* 2000). For example, to determine the RNV in the size of disturbance patches in sub-boreal forests, an area much larger than the average fire size must be analyzed (Cumming and Burton 1996). Scaling up from stand-level reconstructions to a landscape-level description can also be problematic, yet multiple spatial scales must be examined because drivers operating at different scales influence ecological processes. For example, regional climate can drive long-term trends in fire frequency, whereas smaller-scale factors, such as topographic position and fuel conditions, drive where and how fires burn (Lertzman and Fall 1998; Riccius 1998). Disturbance regimes and structures vary with topographic position and many components of the RNV likely need to be defined separately for different portions of the landscape. Variability of processes and structures through space and time can also arise solely from stochastic factors and limit our ability to interpret trends (Lertzman *et al.* 1998).

Types of Information and Methods for Determining Range of Natural Variability

Describing the RNV in forests requires temporal and spatial information about forest dynamics for the chosen time period and site. Natural archives (e.g., pollen and charcoal preserved in soil or lake sediments, and animal deposits such as packrat middens) can provide long-term information on vegetation dynamics (Swetnam *et al.* 1999). Tree rings can record short- to moderate-term responses to climatic variation and disturbances. Documentary archives (e.g., photographs, journals, surveys, plots, and weather records) can also supply information on the state of ecosystems shortly after European settlement. Each source of data is limited in how well it describes the RNV because of temporal and spatial censorship (Swetnam *et al.* 1999). For example, radiocarbon dating of charcoal is expensive and thus sampling is, in most cases, temporally rich but spatially poor. Fire scars recorded in tree rings are easier to sample and are spatially rich, but temporally less extensive (Lertzman *et al.* 1999). Because of these limitations, researchers must often combine multiple lines of evidence to estimate the RNV.

Spatially explicit modelling, which involves repeated projections through long time periods and substitutes space for time in sampling (Dorner 2002), may allow us to overcome some of the uncertainties in the historical record. The resulting simulated variability through time provides an estimate of RNV. Modelling requires parameterization based on expert knowledge and site-specific information from field sampling. By simplifying complex processes, modelling has its own sources of uncertainty. Sensitivity analyses can help identify which sources of uncertainty have the greatest influence on conclusions. Evaluating whether RNV has been adequately determined requires assessing the temporal and spatial resolution of sampling and methods of analysis (see evaluation checklist in Drever and Wong 2002).

Several descriptions of the RNV have been used: the range between the maximum and minimum observed values; and the distribution of observed values displayed between standard deviations in histograms, box-plots, or bivariate centroids (e.g., Wong 1999; Dorner 2002).

Practical Application of Range of Natural Variability

The application of the RNV encounters practical, temporal, and spatial limits in the data because of our inability to measure the full range and all aspects of natural variability. Thus, managers use a subset of the RNV instead. We use the term *apparent range of variability* (ARV) to describe actual measures of natural variability on a specific landscape (Figure 2; Wong 1999). Apparent range of variability conveys that the definition depends on the temporal and spatial extent of available data and information. Explicit statement of the temporal extent, spatial context, and sources of data is key when using the term ARV because different interpretations are possible (Figure 2). Distributions of values describing ARV can be

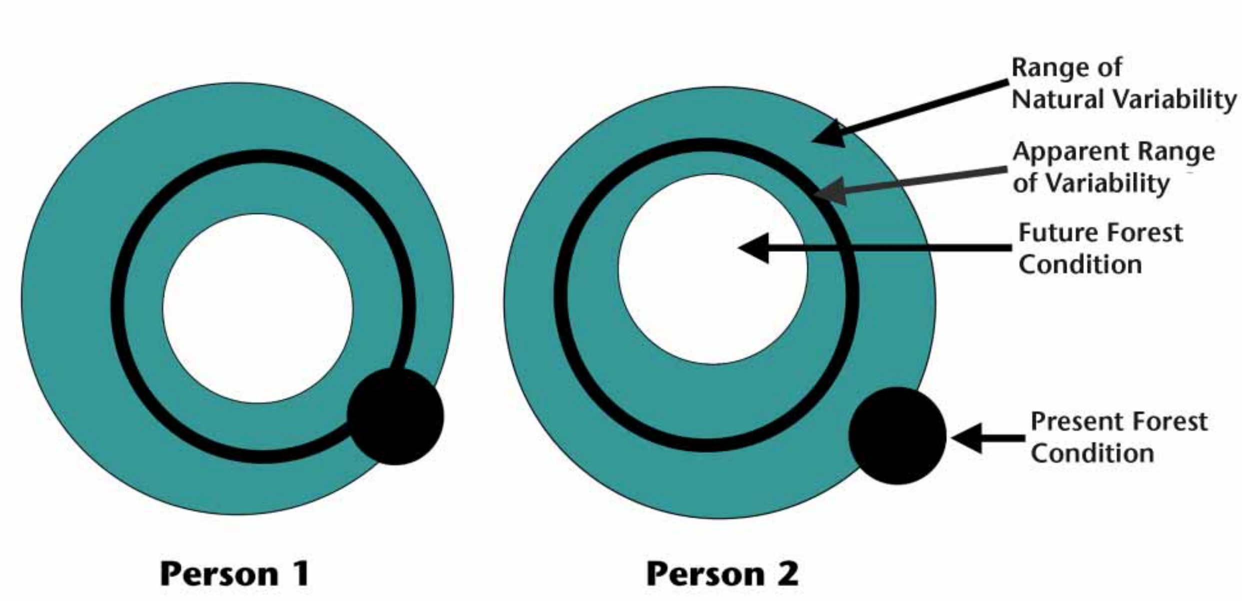

FIGURE 2. The full range of natural variability (RNV) determines the hypothesized ecological boundaries of conditions assumed to be sustainable. The apparent range of variability (ARV) is a subset of the RNV, which is captured by sampling and modelling. Present conditions in most landscapes do not represent the full RNV and may even lie outside of the RNV. Desired future conditions are those determined from ARV, present conditions, and socio-economic values. Evaluation of the same information on ARV and different socio-economic values could lead to different interpretations. In this example, Person 1 believes that current conditions are closer to ARV and desired future conditions than Person 2.

truncated to reflect censorship and confidence in the record (e.g., using 95% of the distribution as we are too uncertain about the remaining 5%). The sensitivity of conclusions about the conditions of current ecosystems to various confidence levels in the record should be tested. Under ecosystem management, sustainable and achievable objectives for desired future forest conditions are not only a function of ARV, but also of current conditions and socio-economic values—these are discussed more in the example in the next section.

In forest management, the ARV can be used when mimicking the characteristics of ecological processes or their resulting stand or landscape structure in setting management objectives and developing landscape-level and site plans. The ARV could be described in ecological processes such as:

- disturbance regimes: the frequency, severity, extent, and spatial pattern of fire, insects, wind, and other disturbance agents; and
- stand dynamics: tree growth, regeneration, nutrient cycling, and the stand's response to various disturbance agents.

The ARV in forest structure could also be applied to elements such as:

- stand structure: the distribution of dead and live tree basal area, etc.;
- landscape pattern: stand types and patch size distribution; and
- composition: the abundance and distribution of vegetation and wildlife.

An Example in Estimating and Applying Range of Natural Variability

In the following section, we present six steps for applying the RNV concept to forest management:

1. Define objectives in terms of RNV
2. Build an information base and estimate the ARV
3. Compare current conditions to the ARV
4. Identify socio-economic conditions that influence the application of the ARV
5. Determine desired future forest conditions and methods to achieve them
6. Apply adaptive management

We use the Interior Douglas-fir (IDF) biogeoclimatic zone in Lignum Ltd.'s Innovative Forest Practices Agreement (IFPA) area near Williams Lake (Figure 3) to illustrate each step. To date, most of Lignum's work has been on Steps 1 to 4.

Step 1: Define Objectives in Terms of Range of Natural Variability

Lignum's objective is to manage the IDF landscape in the IFPA area so that it functionally and structurally occupies a reasonable portion of the ARV at the stand and landscape levels within social, economic, and operational constraints.

Step 2: Build an Information Base and Estimate the Apparent Range of Variability

To estimate the ARV, we must first identify what attributes we are trying to describe—that is, what are the most important processes and structures in the IDF? Lignum held a workshop for local foresters, as well as forest and fire ecologists, to discuss the processes influencing the IDF. From this workshop, a conceptual framework of processes and their impacts on IDF stand and landscape characteristics was outlined (Lignum Ltd. 2001). Across most of the IDF in the IFPA area, fire was identified as the most influential process, one that historically interacted with other important disturbance agents, such as Douglas-fir beetle (*Dendroctonus pseudotsugae*) and mountain pine beetle (*Dendroctonus ponderosae*). Important landscape (e.g., multi-aged stands) and stand characteristics (e.g., large trees and large, but few, pieces of coarse woody debris) were also identified. Thus, the initial focus has been on characterizing the ARV in fire regimes and important landscape and stand attributes.

Discussions also helped to define the temporal and spatial scale of the ARV. The time frame for the ARV should extend several hundred years, recognizing the potential influence of the Little Ice Age on fire regimes during 1400–1900 AD (Miller and Woolfenden 1999; Smith and Desloges 2000). Because First Nations peoples likely inhabited the Cariboo Region for thousands of years, the definition includes aboriginal burning of forests and grasslands. Although the extent is unknown, aboriginal burning did occur—Elders of the Canoe Creek and Esketemec First Nation in the southern portion of the IFPA area remember burning in early spring to maintain meadows and open forests (Wong 2000). The time frame for the ARV should end between 1860 and 1920 when Europeans began to influence the IDF; different dates are likely needed for different areas.

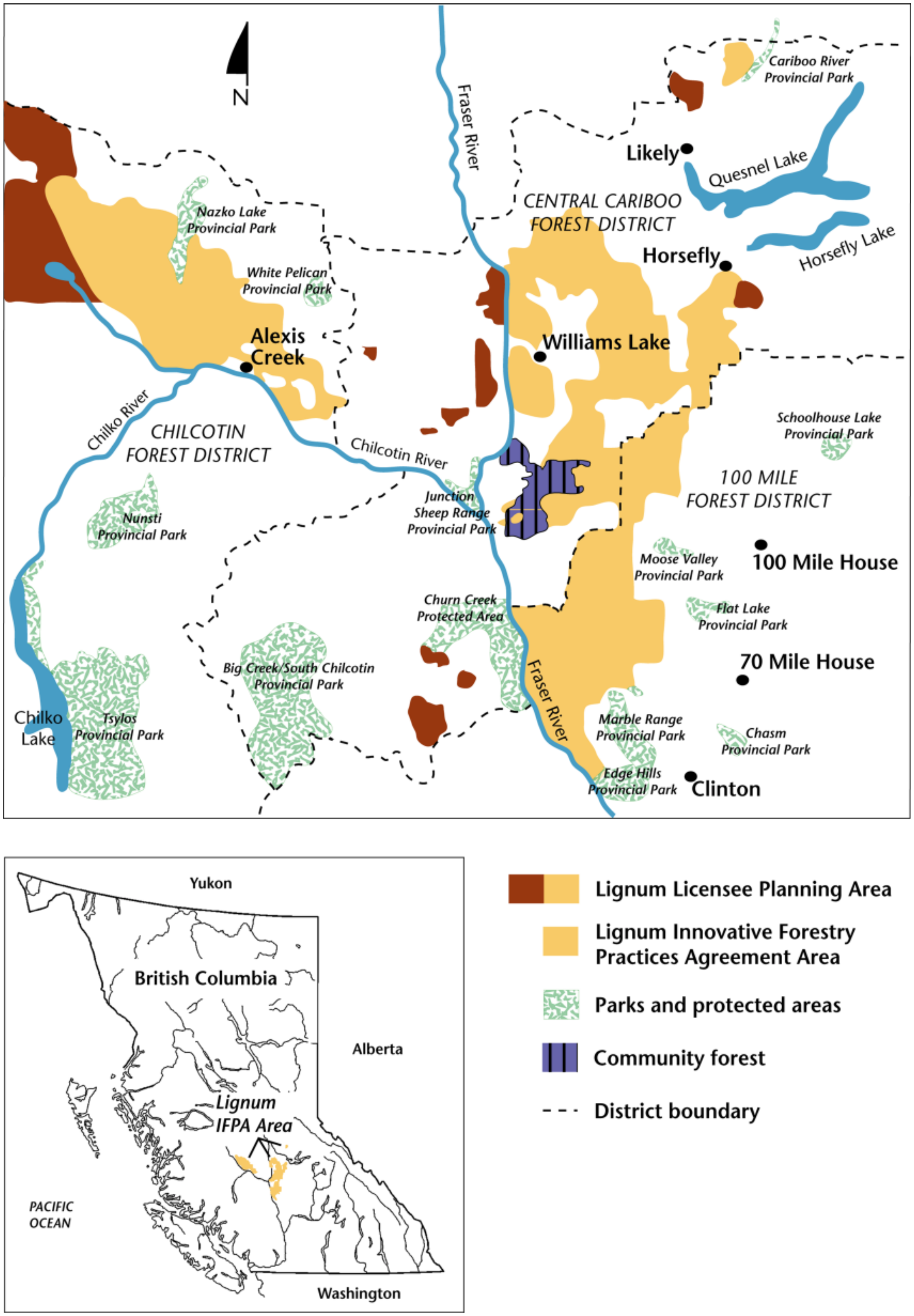

FIGURE 3. Location of Lignum Ltd.'s Innovative Forest Practices Agreement (IFPA) area in British Columbia. The Interior Douglas-fir biogeoclimatic zone forms 57% of the 610 000 ha in the IFPA area, most of it south of Williams Lake.

European fur traders first settled along the Fraser River between Williams Lake and Quesnel in 1821 and thousands of miners began arriving in 1859 (Weir 1955; Patenaude 1995). Ranching began in grasslands and adjacent forests in the 1860s, but large areas of continuous forest were not grazed or otherwise altered until the 1920s (Weir 1955; McLean 1982). Aerial fire suppression began in the 1960s (J. Parminter, B.C. Ministry of Forests, pers. comm., 2000).

The spatial scale at which we describe the ARV of fire regimes must include areas that represent the variation in the IDF. Note that while past fire regimes and stand structure have been reconstructed using field-based evidence (e.g., Gray *et al.* 1998; Riccius 1998) and documentary sources of evidence (Klenner *et al.* 2001) for IDF locations outside of the Cariboo Region, the ARV requires data and information collected specific to the IFPA area. Efforts have focused on describing the largest part of the landscape first—most of the information collected has been specific to the mesic and submesic portions of the Interior Douglas-fir, dry cool subzone Fraser variant (IDFdk3), which forms 70% of the IDF in the IFPA area.

Building an information base to quantify the ARV should combine comparative analyses and test multiple, independent data sources and methods to increase objectivity and confidence in historical interpretations (Swetnam *et al.* 1999). Lignum chose to compare and integrate field-collected data on past fire regimes and stand structure with spatially explicit landscape modelling of fires and stand dynamics. Field-collected fire scar and tree age data provided the only evidence of forest structure that consistently dated back to 1700 or earlier (Iverson *et al.* 2002) and helped parameterize the model. Modelling was pursued to extend the temporal and spatial picture of the ARV in stand structure at the landscape level, to compensate for missing information, and to test different hypotheses and project future conditions (Cumming and Wong 2002, 2003).

Field-based Fire History Study

Because fire regimes and stand structure differ depending on ecological conditions, we chose to sample relatively level mesic to submesic sites in the IDFdk3 to reduce the complexity but capture most of the landscape (Iverson *et al.* 2002). To facilitate historical stand reconstruction, we only sampled stands with no history of forest management. To decrease the intensity of field sampling, the study resampled existing stand structure plots spread extensively across the IFPA area for fire history. We sampled the diameter and species of all trees, a subsample of tree ages, and a minimum of six fire scar samples in a 20-ha area centred on the plot. Coarse woody debris and snags were tallied to determine the full potential density of historical stands. Lines of evidence that were used to complement these field-collected data included weather and fire records extending back to approximately 1900, historical photos, and anecdotal accounts of traditional aboriginal burning. The ARV in fire and stand structure is primarily a function of the temporal extent of the tree ring record in the IFPA area's IDF stands (dependent on both the lifespan of Douglas-fir and lodgepole pine [*Pinus contorta*] and the extent of unlogged forests in the IDF) and the spatial location and extent of this remaining tree ring record. Distributions (histograms and boxplots) of fire frequency (fire intervals; Figure 4) and severity (age-class distributions) were used to describe the ARV in fire regimes. Two fire regimes were identified: a predominantly understorey fire regime in lower-elevation, Douglas-fir–dominated stands and a mixed-severity fire regime dominated by low-severity fire in other stand types. A comparison of historical and current stand structures and fire intervals provided indications to retain large, old trees and open stand structures, to reduce densities of smaller-diameter trees, and to manage fuels to reduce wildfire threat on the landscape.

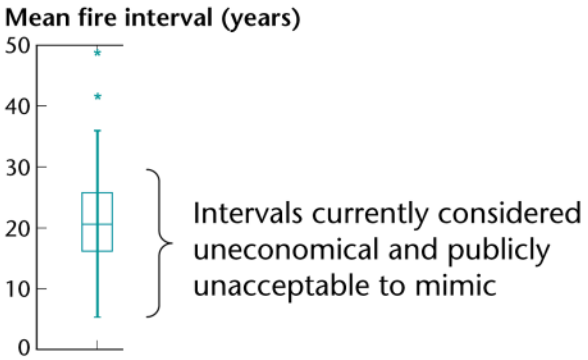

FIGURE 4. Mean fire interval distributions for all plots ($n = 44$) in the IDFdk3, IFPA area from Iverson *et al.* (2002). Apparent range of variability could be where 50% of the values lie as indicated by the box, the full range, or some other measure. In this example, intervals more frequent than 30 years are currently considered uneconomical to mimic with harvesting re-entries into managed Douglas-fir stands and publicly unacceptable to mimic with prescribed burning. It may be economically feasible to space small trees to mimic mean fire interval < 30 years.

Pilot Model on Past Fire Dynamics

A new model tailored to low- and mixed-severity natural disturbance regimes in interior Douglas-fir forests in British Columbia had to be developed because available models for similar ecosystems in the United States are too mechanistic and parameter-intensive. The spatially explicit landscape model developed for Lignum is built around relationships between tree diameter and crown ratios, heights, and probabilities of growth and survival using field-collected growth and yield data specific to the IFPA area (see Cumming and Wong 2002, 2003). Reconstructed stand structures, fire frequency, and severity from the fire history study described above were used to initialize the modelled landscape and calibrate fire spread probabilities and size. The model has several stochastic components (e.g., location of fire starts) that are intended to capture the range of variation in uncertain and unquantified processes. The model can be used to simulate different scenarios, such as the historical landscape under pre-European fire regimes, and to project the current landscape into the future under current fire and harvesting regimes. Monte Carlo simulations of the first scenario allow us to estimate the ARV in various stand attributes—for example, live and dead stand basal area or the density of large trees were estimated using spatial patterns from maps produced at different points in time and distributions of landscape averages over time. Figure 5 shows that, through 300 years of the pre-European fire regime, the density of Douglas-fir saplings averaged between *a* and *b* trees per hectare on the landscape. Under post-European conditions (e.g., less frequent fires and lower probability of escaped fires), the density of saplings increased up to *c* trees per hectare.

Step 3: Compare Current Conditions to the Apparent Range of Variability

The current condition of both individual stands and the landscape should be compared to the ARV. Current conditions can be described from permanent sample plots, forest inventory, operational timber cruises, and silviculture prescriptions or site plans. At the stand level, the historical stand reconstructions from the fire history study were compared with the current distribution of tree species and diameters in a subsample of Vegetation Resources Inventory plots. Results show that stands were historically more open, with more large trees on mesic and submesic sites (Iverson *et al.* 2002). Modelling of the pre-European fire regime supported the historical dominance of this type of stand structure on the landscape (Cumming and Wong 2002, 2003). In comparing current fire intervals with historical fire intervals, we found that the current fire-free interval is two to three times greater than the historical mean and that 80% of plots ($n = 44$) have a present fire-free interval greater than the historic maximum fire-free interval (Iverson *et al.* 2002). This comparison can direct stand-level silviculture prescriptions and prescribed burning. Because of the relatively long interval since the last fire, prescribed burning in these stands should be preceded by thinning to decrease the risk of a high-intensity burn.

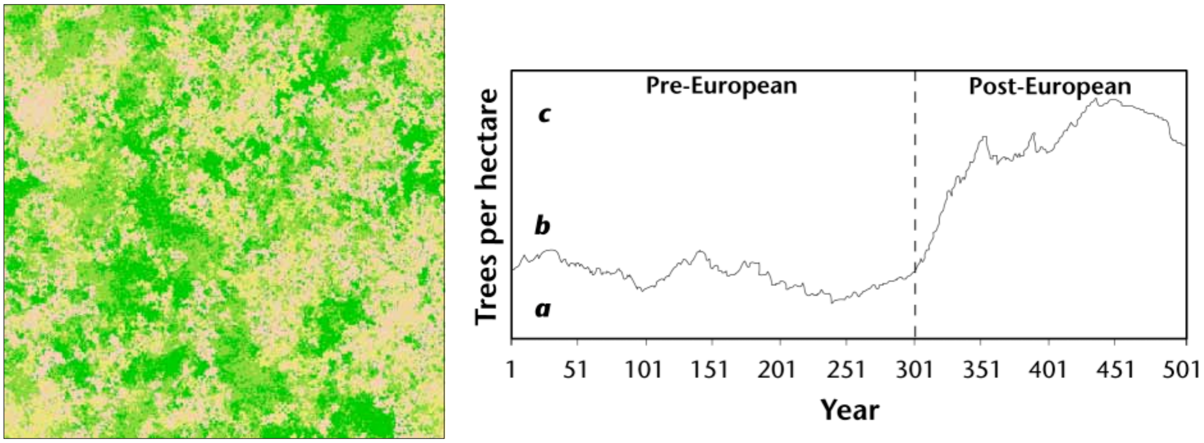

FIGURE 5. Output from a pilot version of a spatially explicit landscape model of IDF fire and stand dynamics. The map on the left illustrates the density of large Douglas-fir at a point in time over a 90 000-ha landscape (dark green indicating higher densities). The graph on the right illustrates average sapling density per 1-ha cell over the landscape resulting from simulated pre-European fire regimes and post-European fire regimes (from Cumming and Wong 2002). This output is for conceptual purposes only.

To evaluate forest management over a large landscape in regards to the ARV in processes and attributes, the ARV must be estimated for attributes that are ecologically meaningful and can be described well across a large area. Lignum has developed a method to classify similar stand structure in the IDFdk3 (ForesTree Dynamics and J.S. Thrower and Associates 2002). The method uses non-parametric techniques to analyze cumulative size distributions and stem maps of growth and yield, permanent sampling, and stand structure plots in the IFPA area. An algorithm was developed to group similar plots based on the proportion of area occupied by trees under a range of diameter thresholds and spatial scales. In field operations, stands can be classified as a certain stand type using a key based on the proportion of basal area in different tree size classes (Farnden *et al.* 2003). Growth projections and suitable silviculture and harvesting prescriptions are being developed for each of 17 stand types (Bowering and Reimer 2003). The stand structure classification can be used to classify simulated historical landscapes using the model developed by Cumming and Wong (2003), and thus compare the distribution of stand structure on current landscapes with the ARV on past landscapes (Figure 6). This comparison can influence landscape-level strategic planning by guiding management to maintain or increase types of stand structure that were historically common, but are now poorly represented on the landscape.

Step 4: Identify Socio-economic Conditions that Influence the Application of the Apparent Range of Variability

Socio-economic values can constrain the degree to which the ARV in fire regimes and structure is incorporated into forest management. Legislated requirements of the *Forest and Range Practices Act* and the Cariboo–Chilcotin Land

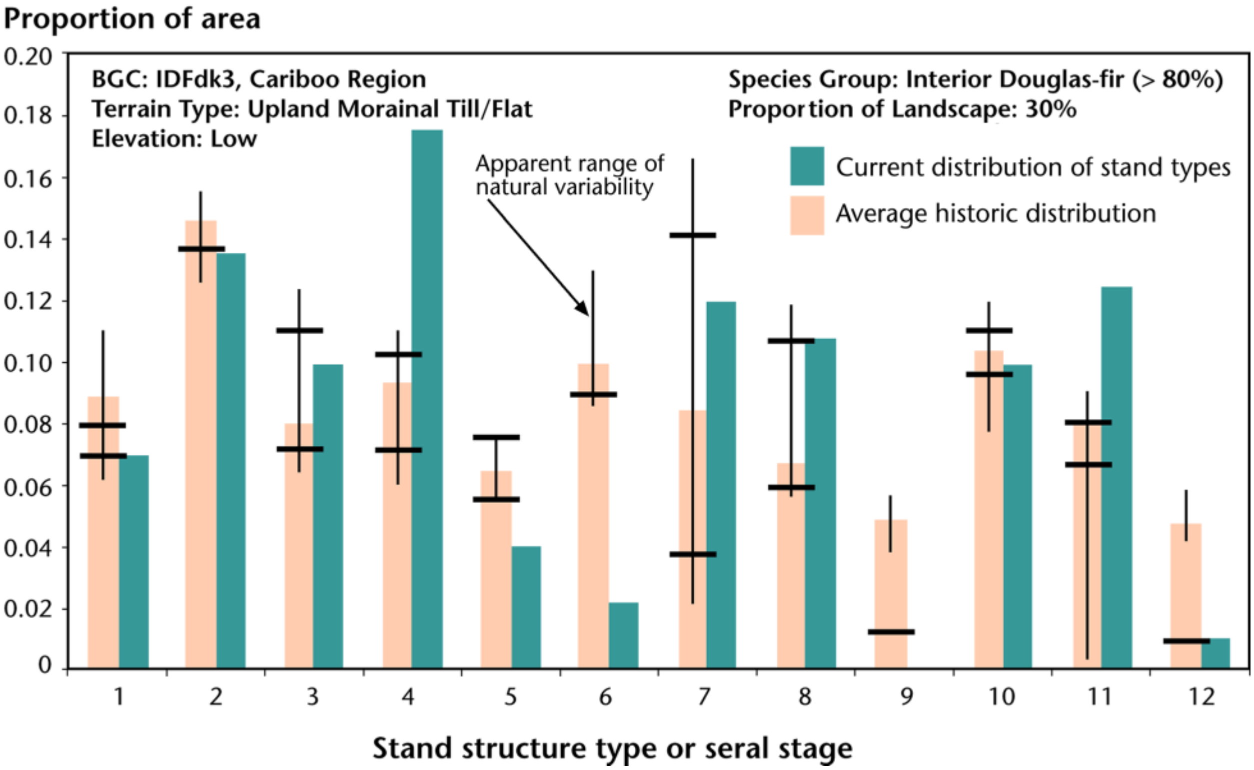

FIGURE 6. The average historic and current distribution of stand types in a hypothetical IDFdk3 landscape for a specific terrain type. The ARV in historic proportions is indicated by the vertical line in the bar. The proportion of area that falls within each stand type in the desired future forest condition would be based on the ARV and socio-economic values (indicated by bold horizontal bars). In this example, the objective would be to manage the future landscape within, or close to, the bold horizontal bars at any point in time—some stand types would be managed close to the ARV, although the proportion of other stand types would be influenced more by socio-economic factors. Figure courtesy of I. Moss, ForesTree Dynamics Ltd.

Use Plan (CCLUP) govern forest management in the IFPA area (Lignum Ltd. 2000). Although the *Biodiversity Guidebook* of the earlier Forest Practices Code directs forest management to emulate natural disturbance patterns (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995), the grouping of ecosystems into broad "natural disturbance types" does not reflect the variability in disturbance patterns; more site-specific information is needed to refine these guidelines. The CCLUP is derived from a negotiated public planning process that allocates land to various uses and specifies management targets indicative of socio-economic values. Timber targets were established to provide access to the majority of each zone while meeting other resource targets. These targets include: maintaining adequate mule deer winter range, visual quality around scenic areas, current levels and distribution of cattle grazing, road and mining access to most of the zone; and protecting identified watersheds for salmon and riparian habitat. The CCLUP also includes managing for biodiversity targets (seral or structural distributions) once they are established under the Regional Biodiversity Conservation Strategy.

Managing for these targets can affect the application of the ARV. For example, the density of small-diameter Douglas-fir, which is high in the understorey over much of the IDF, is outside of the RNV in IDF forest structure owing to fire exclusion and grazing (Figure 5; Cumming and Wong 2002; Iverson *et al.* 2002). Introducing the full range of fire frequency over the entire landscape is currently operationally expensive and socially unacceptable because of smoke concerns and liability. Thus, managing for the ARV in sapling density would require a combination of active management and tools, such as prescribed burning, thinning, and less protection of regeneration during harvesting. Because 80% of 44 sampled stands representative of the IDFdk3 in the IFPA area have a present fire-free interval greater than the historic maximum fire-free interval (Iverson *et al.* 2002), most stands will require thinning before fire is reintroduced. Managing for the ARV in sapling density would also require changing stocking guidelines, which direct certain levels of regeneration before a cutblock can be declared free-growing.

Certain management and market environments can offer incentives to manage for the ARV. For example, the increase in small-diameter Douglas-fir coupled with fuel accumulation from fire exclusion is thought to increase the potential for large stand-replacing fires outside the RNV in some stands. Currently, forest licensees are not responsible for fire hazard on the landscape, but evolving fire protection responsibilities in upcoming forest policy changes may provide incentives to licensees to use the ARV in sapling density to rationalize certain fire proofing management. The use of the ARV can also be constrained by how economically viable it is to incorporate into operations. Determining economic viability will require ascertaining the implications of managing for ARV on growth and yield, forest health, timber values, and harvesting costs. Currently, few milling or market opportunities are available for small-diameter Douglas-fir.

Step 5: Determine Desired Future Forest Conditions and Methods to Achieve Them

Social and economic values should be incorporated such that forest management maximizes the occupancy of the ARV. In Step 3, we determined that current fire intervals lie outside the ARV (Iverson *et al.* 2002). In Step 4, we determined that under current economic and regulatory constraints, we could not reintroduce the full range of past fire frequencies. Using the spatially explicit model (Cumming and Wong 2002), we can project what the future landscape will look like under the current fire regime of longer fire-free intervals (Figures 5 and 6). We can also project the future landscape under different scenarios that combine a moderate fire frequency with various partial-cutting surrogates. Comparing these projections with the ARV will aid decisions on how we want the future forest to look and behave. Because determining the future forest subjectively weighs various socio-economic values with the ecological direction given by the ARV, decision making must be transparent and well documented.

With some innovation we can emulate the ARV of structural effects from a regime of frequent, primarily low-severity fires. Lignum currently plans to harvest in the IDF every 30–60 years—a period which lies outside the ARV in fire frequency—because it is considered too expensive and inefficient to re-enter more often. It may be economically feasible to space small trees to mimic a mean fire interval of less than 30 years. To emulate fire regimes in the IDF, Lignum could re-enter at intervals outside of the ARV in fire-return intervals, but could maintain the ARV in fire severity and forest structure through the proportion and composition of what is removed. Evidence of mixed-severity disturbance regimes in lodgepole pine-dominated and mixed Douglas-fir–lodgepole pine stands suggests the proportion and composition of what is removed should vary over the landscape (Iverson *et al.* 2002). Process-based RNV can be reintroduced on portions of the landscape using prescribed fire. The exact historical spatial pattern and density of a stand does not need to be reconstructed through selective logging and fire, but resulting structure should fall within the structural ARV determined from many stands. Additionally, stand-level plans should strive to maintain structural variability between stands rather than allowing all stands to tend towards the mean of attributes within the ARV.

Landscape- and stand-level management plans aid in achieving desired future forest conditions. However, fixed administrative boundaries (e.g., private land and old-growth management areas) inherently conflict with the RNV concept because the boundaries of natural disturbances vary over time. Fixed forest policy and regulations (e.g., those regulating the utilization of coarse woody debris and worker safety around snags) also restrict variability. In general, highly regulated forest management based on a multitude of inflexible rules defeats the rationale behind applying the RNV concept (Holling and Meffe 1996).

Management towards the desired future forest condition should be spatially prioritized. Priorities for choosing stands to return to the ARV could aim to reduce the risk of catastrophic wildfire. The Wildfire Threat Rating System could be used to determine areas at greatest risk by considering all values to be protected, the risk of ignition, suppression capabilities, and fire behaviour (Hawkes and Beck 1997). This approach may determine that some areas should be managed fully within the ARV to maintain values at risk and that other areas should be managed for greater timber production and other values while also moving closer to the ARV.

Step 6: Apply Adaptive Management

Given that our understanding of historical forest structure and processes—as well as management techniques to maintain or imitate these—is imperfect, forest management should adapt in response to new information. Management objectives should be treated as hypotheses that are tested through rigorous monitoring and modified as needed through adaptive management (Holling and Meffe 1996). In Step 4, we determined that under current economic and regulatory constraints, we could not reintroduce the full range of past fire frequencies or historical stand structure. However, as policy, technology, and markets evolve, we may be able to move closer to occupying the full ARV. For example, the public's perception and tolerance of smoke from prescribed fires may increase if large wildfires burn homes. This change, coupled with financial incentives such as reduced stumpage, could make it viable for prescribed burning to be incorporated into forest management. Markets for small-diameter Douglas-fir may develop due to efforts by the United States Forest Service in their Small Wood Utilization Program. In stands considered to be ingrown with small-diameter Douglas-fir due to fire exclusion, these markets could make harvesting directed towards restoring historical stand structure more economically viable.

> *The future challenges for the implementation of the RNV illustrate a demand for explicit statement of data sources and scales and a commitment to long-term adaptive management.*

Our discussion centres on the ARV in fire regimes and is meant to provide rationale and direction for ecosystem-based management. We did not discuss interactions between fire and other disturbance agents. Historic fire regimes are hypothesized to maintain forest structure, which reduces some forest health risks (e.g., reduced canopy layers decrease western spruce budworm [*Choristoneura occidentalis*] susceptibility) (Anderson *et al.* 1987). The severity of mountain pine beetle attacks appears to affect the intensity and severity of subsequent fires (Turner *et al.* 1999). As new information on past dynamics of fires, insects, and other disturbances in the IFPA area becomes available from research and monitoring, forest management can be adapted. Lignum has initiated planning for adaptive management trials to return some stands closer to their ARV.

Future Challenges

We have illustrated the challenges in defining and using the concept of the range of natural variability. One of the challenges of interpreting and applying RNV is future climate change. Models project warming at the rate of 1–4°C per century, with the greatest rate of warming in the Interior of British Columbia (B.C. Ministry of Environment, Lands and Parks 2000). Because of the strong historical coupling between fires and La Niña events in the Cariboo IDF, climate change will likely affect future fire regimes (Daniels and Watson 2003). How can the RNV we describe today be interpreted within this context? Do we manage forests based on disturbance regimes that occurred under past climatic conditions or do we anticipate future climatic conditions? Understanding the climatic context of the ARV used as reference conditions for management is essential for these decisions. The future challenges for the implementation of the RNV illustrate a demand for explicit statement of data sources and scales and a commitment to long-term adaptive management.

Acknowledgements

Much of this paper stems from discussions and work done by Lignum's IDF Stand Structure Working Group (Greg Ashcroft, Dave Conly, Ken Day, Tracy Earle, John Liscomb, Ian Moss, and the two authors). We also thank Bob Gray, Laurie Kremsater, Ken Lertzman, Kim Peel, Dave Peterson, and Terry McIntosh for reviewing and providing insightful comments on an earlier version of this paper, which was funded by Forest Renewal BC through Lignum Ltd.

References

Allen, T.F.H. and T.W. Hoekstra. 1991. Role of heterogeneity in scaling of ecological systems under analysis. *In* Ecological heterogeneity. J. Kolasa and S.T.A. Pickett (editors). Springer-Verlag, New York, N.Y.

Anderson, L., C.E. Carlson, and R.H. Wakimoto. 1987. Forest fire frequency and western spruce budworm outbreaks in western Montana. Forest Ecology and Management 22:251–260.

Bowering, M. and D. Reimer. 2003. Assignment of stand structures and the development of growth patterns for IDF types. Final report prepared for Lignum Ltd. Available from: *www.lignum.com*

British Columbia Ministry of Environment, Lands and Parks. 2000. Environmental trends in British Columbia 2000. Available from: *www.elp.gov.bc.ca/sppl/soerpt/etrends-2000.pdf* [Accessed March 1, 2001]

British Columbia Ministry of Forests and British Columbia Ministry of Environment. 1995. Biodiversity guidebook. Forest Practices Code of British Columbia. Victoria, B.C.

Cissel, J.H., F.J. Swanson, and P.J. Weisberg. 1999. Landscape management using historical fire regimes: Blue River, Oregon. Ecological Applications 9:1217–1231.

Cumming, S. and C. Wong. 2002. Pilot modelling of past fire dynamics in the IDF. Report to Lignum Ltd. Available from: *www.lignum.com*

________. 2003. Characterizing the range of natural variability in dead wood in the IDFdk3. Report to Lignum Ltd. Available from: *www.lignum.com*

Cumming, S.G. and P.J. Burton. 1996. Boreal mixedwood may have no "representative" areas: some implications for reserve design. Ecography 19:162–180.

Daniels, L.D. and E. Watson. 2003. Climate–fire–vegetation interactions in the Cariboo Forests: a dendrochronological analysis. Forest Innovation and Investment Forest Research Program Report.

Dorner, B. 2002. Forest management and natural variability: the dynamics of landscape pattern in mountainous terrain. PhD thesis. Simon Fraser University, Burnaby, B.C.

Drever, C. and C. Wong. 2002. Range of natural vari-ability: what does it mean for sustainable forest management? Ecoforestry 17:11–12.

Farnden, C., I. Moss, and T. Earle. 2003. Prototype field guide for identifying stand structure classes in the Cariboo Forest Region. Report prepared for Lignum Ltd. Available from: *www.lignum.com*

ForesTree Dynamics Ltd. and J.S. Thrower and Associates Ltd. 2002. Stand structures and their classification. Report to Lignum Ltd. Available from: *www.lignum.com*

Fulé, P.Z., W.W. Covington, and M.M. Moore. 1997. Determining reference conditions for ecosystem management in ponderosa pine forests. Ecological Applications 7:895–908.

Gray, R.W., E. Riccius, and C. Wong. 1998. Comparison of current and historic stand structure in two IDFdm2 sites in the Rocky Mountain Trench. Report to B.C. Ministry of Forests.

Hawkes, B.C. and J. Beck. 1997. A wildfire threat rating system for the McGregor Model Forest. Final report submitted to the McGregor Model Forest Association.

Holling, C.S. and G.K. Meffe. 1996. Command and control and the pathology of natural resource management. Conservation Biology 10:328–337.

Iverson, K.E., R.W. Gray, B.A. Blackwell, C. Wong, and K.L. MacKenzie. 2002. Past fire regimes in the Interior Douglas-fir dry cool subzone Fraser variant (IDFdk3). Report to Lignum Ltd.

Klenner, W., L. Kremsater, and A. Arsenault. 2001. Natural and managed disturbances in NDT4 forest types: a literature review and analysis of issues that relate to future management directions. B.C. Ministry of Forests, Kamloops, B.C. Unpublished draft report.

Landres, P.R., P. Morgand, and F.J. Swanson. 1999. Overview of the use of natural variability concepts in managing ecological systems. Ecological Applications 9:1179–1188.

Lertzman, K. and J. Fall. 1998. From forest stands to landscapes: spatial scales and the roles of disturbances. *In* Ecological scale theory and applications. D.L. Peterson and T.V. Parker (editors). Columbia University Press, New York, N.Y.

Lertzman, K., J. Fall, and B. Dorner. 1998. Three kinds of heterogeneity in fire regimes: at the crossroads of fire history and landscape ecology. Northwest Science 72:4–23.

Lertzman, K.P., B. Dorner, J. Fall, and E.K. Heyerdahl. 1999. Linking paleoecology and forest management: applying lessons about forest landscapes in space and time. Bulletin of Ecological Society of America 180(3):24.

Lignum Ltd. 2000. Innovative Forestry Plan Agreement: state of the forest technical document. Available from: *www.lignum.com*

________. 2001. Ecological processes and their impacts on IDF stand and landscape characteristics. Workshop proceedings, February 7, 2001. Available from: *www.lignum.com*

Long, J.N. and F.W. Smith. 2000. Restructuring the forest: goshawks and the restoration of southwestern ponderosa pine. Journal of Forestry 98:25–30.

McLean, A. 1982. History of the cattle industry in British Columbia. Rangelands 4:130–133.

Miller, C.I. and W.B. Woolfenden. 1999. The role of climate change in interpreting historical variability. Ecological Applications 9:1207–1216.

Moore, M.M., W.W. Covington, and P.Z. Fulé. 1999. Reference conditions and ecological restoration: a southwestern ponderosa pine perspective. Ecological Applications 9:1266–1277.

Morgan, P., G.H. Aplet, J.B. Haufler, H.C. Humphries, M.M. Moore, and W.D. Wilson. 1994. Historical range of variability: a useful tool for evaluating ecosystem change. Journal of Sustainable Forestry 2:87–111.

Patenaude, B.C. 1995. Trails to gold. Horsdal and Schubart Publishers Ltd., Victoria, B.C.

Quigley, T.M. and S.J. Arbelbide. 1997. Executive summary: landscape dynamics. *In* An assessment of ecosystem components in the Interior Columbia Basin and portions of the Klamath and Great Basins. T.M. Quigley and S.J. Ardelbide (editors). U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oreg. Volume 1. General Technical Report PNW-GTR-405.

Riccius, E. 1998. Scale issues in the fire history of a fine grained landscape. MRM thesis. Simon Fraser University, Burnaby, B.C.

Smith, D.J. and J.R. Desloges. 2000. Little ice age history of Tzeetsaytsul Glacier, Tweedsmuir Provincial Park, British Columbia. Géographie Physique et Quarternaire 54:135–141.

Swanson, F.J., J.A. Jones, D.O. Wallin, and J.H. Cissel. 1994. Natural variability—implications for ecosystem management. *In* Eastside Forest Ecosystem Health Assessment. Volume II: Ecosystem management: principles and applications. M.E. Jensen and P.S. Bourgeron (editors). U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station, Portland, Oreg., General Technical Report PNW-GTR-318, pp. 80–94.

Swetnam, T.W., C.D. Allen, and J.L. Betancourt. 1999. Applied historical ecology: using the past to manage for the future. Ecological Applications 9:1189–1206.

Turner, M.G., W.H. Romme, and R.H. Gardner. 1999. Prefire heterogeneity, fire severity, and early postfire plant reestablishment in subalpine forests of Yellowstone National Park, Wyoming. International Journal of Wildland Fire 9:59–77.

Weir, T.R. 1955. Ranching in the southern interior plateau of British Columbia. Department of Mines and Technical Surveys, Ottawa, Ont. Geographical Branch Memoir 4.

Wimberly, M.C., T.A. Spies, C.J. Long, and C. Whitlock. 2000. Simulating historical variability in the amount of old forests in the Oregon coast range. Conservation Biology 14:167–180.

Wong, C.M. 1999. Memories of natural disturbances in ponderosa pine–Douglas-fir age structure, southwestern British Columbia. MRM thesis. Simon Fraser University, Burnaby, B.C.

________. 2000. Natural disturbance regimes in the Cariboo Region: what is known to guide forest management? Report to Lignum Ltd.