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An old-growth index for Douglas-fir stands in portions of the Interior Douglas-fir zone, central British Columbia

O.A. Steen[1], R.J. Dawson[2], and H.M. Armleder[3]

Abstract

We describe a quantitative old-growth index for Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) stands in two Interior Douglas-fir (IDF) biogeoclimatic variants (dk3 and dk4) in the central interior of British Columbia. The index uses stand structure data including basal area of very large (≥ 57.5 cm DBH) and large (≥ 37.5 cm DBH) trees, density of small (< 27.5 cm DBH) trees, tree size variability, canopy complexity, density of declining and dead trees, and occurrence of canopy gaps. Three forms of the index were developed to accommodate different objectives and levels of data availability. Index values are grouped into four classes (early seral, mid-seral, mature, and old growth). Qualifiers of these classes provide additional descriptions of old-growth structural development as well as guidance for designing management practices to enhance old-growth development. A link is provided to a Microsoft Excel spreadsheet that can be used to calculate old-growth index values using each form of the index.

KEYWORDS: *British Columbia, Douglas-fir forests, forest management, Interior Douglas-fir zone, old growth, old-growth attributes, old-growth index, old-growth management, partial harvesting, seral stage.*

Contact Information

1 Consulting Ecologist, O.A. Steen Consulting, 1740 Richland Drive, Williams Lake, BC V2G 5E2. Email: oasteen@shaw.ca

2 Land and Resources Specialist, B.C. Ministry of Agriculture and Lands, Integrated Land Management Bureau, Suite 201, 172 North 2nd Avenue, Williams Lake, BC V2G 1Z6. Email: Rick.Dawson@gov.bc.ca

3 Wildlife Habitat Ecologist, B.C. Ministry of Forests and Range, Southern Interior Forest Region, 640 Borland Street, Williams Lake, BC V2G 4T1. Email: Harold.Armleder@gov.bc.ca

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Introduction

Forest managers in British Columbia require working definitions of old growth and other successional stages to evaluate the suitability of candidate old-growth management areas and to manage forests for biodiversity conservation (Pojar *et al.* 1992; B.C. Ministry of Forests, Research Branch 1998; MacKinnon 1998; Braumandl and Holt 2000; DeLong *et al.* 2004). However, meaningful and simple definitions of old growth for many forest types have proven elusive. This is attributed to changing perceptions of the values of old growth, variability of old-growth attributes across different sites, and the difficulty of distinguishing classes within the continuum of old-growth attribute development (Hamilton and Pojar 1990; Wells *et al.* 1998).

For operational purposes in British Columbia, old growth and other forest successional stages are most often defined by interpreted stand age (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995; MacKinnon and Vold 1998; DeLong *et al.* 2004). Although stand age has limitations as a definition (DeLong *et al.* 2004), it can provide a reasonable index to the quality of old-growth attributes in stands that develop following a stand-initiating event without subsequent stand-level disturbances. In contrast, stand age is a poor old-growth index in stands that experienced frequent low- to moderate-severity disturbances, which alter only some attributes of a stand. In these forests, the representation of old-growth attributes is a function not only of time since disturbance, but also the frequency and severity of past disturbances and the resulting structural legacies that have contributed to the current stand.

The extensive Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) forests on the dry plateaus and low-elevation slopes of central British Columbia are examples of this latter type of forest. Historically, many stands have experienced repeated low- or mixed-severity wildfires (fire return interval of 15–40 years) that left numerous residual trees (Taylor and Baxter 1998; Iverson *et al.* 2002; Daniels 2005). As well, industrial timber harvesting in recent years has involved predominantly partial cutting, which typically removes 50% or less of the stand volume on each entry and retains trees with a range of sizes. Before the 1980s, larger portions of the stand volume were typically removed and many stands have had multiple entries. The structure and composition of stands, both natural and managed, are the product of past multiple disturbances of varying severity and duration of recovery. Therefore, various researchers have recommended that definitions of old-growth forests of this type in British Columbia should be based on structure and composition attributes rather than age (Hamilton and Pojar 1990; Kneeshaw and Burton 1997; Wells *et al.* 1998; Holt *et al.* 1999).

Meaningful and simple definitions of old growth for many forest types have proven elusive due to changing perceptions of the values of old growth, variability of old-growth attributes across different sites, and the difficulty of distinguishing classes within the continuum of old-growth attribute development.

Definitions of old growth based on structural attributes have been developed for several forest types in North America (e.g., Old-Growth Definition Task Group 1986; Habeck 1990; Franklin and Spies 1991; Spies and Franklin 1991; Mehl 1992; Moir 1992; Kneeshaw and Burton 1998; Wells *et al.* 1998; Hale *et al.* 1999; Lee *et al.* 2000; Frelich and Reich 2003; Morgantini and Kansas 2003; Mosseler *et al.* 2003; Trofymow *et al.* 2003). The following attributes are often included in these definitions:

- average and maximum tree size
- variability of tree sizes and ages
- complexity of forest canopy
- density of large and small trees
- abundance and decay of woody debris
- numbers of snags
- age of oldest trees

The selection of attributes and their required values in a specific definition are generally based on intuitive concepts of old growth, including wildlife values, supported by descriptions and statistical comparisons of stands that are considered to represent old growth. The attributes selected to define old growth and the values required for these attributes are often as much a matter of judgement as quantitative science (Wells *et al.* 1998).

Definitions of old growth have also been based on cohort analyses (Oliver and Larson 1996; Kneeshaw and

Burton 1998). Although the resulting definitions may be consistent with the recognized importance of within-stand ecosystem processes, they are not easily applied to forests with frequent stand-modifying disturbances in which stands have experienced repeated partial disturbances since initial cohort establishment.

Few quantitative definitions of old growth have been developed for dry forests in the Interior of British Columbia (Wells *et al.* 1998). Hamilton and Nicholson (1991) evaluated old-growth criteria used by the U.S. Forest Service and concluded that site-specific criteria should be developed for British Columbia. Definitions that use an index approach and several structural attributes have been developed for stands of the Interior Cedar–Hemlock zone (Holt *et al.* 1999, 2002), the Engelmann Spruce–Subalpine Fir zone (Holt 2000), and the Montane Spruce zone (Holt *et al.* 2001) in southeastern British Columbia, and for boreal and sub-boreal forests in northern British Columbia (Burton *et al.* 1999). DeLong *et al.* (2004) developed a field-scoring tool to assess wildlife habitat values of old-growth stands in the Interior Cedar–Hemlock zone. In the Interior Douglas-Fir (IDF) zone, Quesnel (2002) classed seral stages of stands by matching stand ages predicted from stand structural features to age criteria in the *Biodiversity Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). However, quantitative definitions of old growth, which are independent of age criteria, have not been developed for the extensive Douglas-fir forests of central British Columbia's IDFdk3 and IDFdk4 biogeoclimatic variants.

The project described in this research report was initiated to provide a quantitative old-growth index based on stand structure attributes for Douglas-fir stands on zonal sites (Luttmerding *et al.* 1990) in the IDFdk3 and IDFdk4 biogeoclimatic variants (Steen and Coupé 1997). The project specifically aimed to provide an operational tool that could:

1. identify old growth and other classes of Douglas-fir stands based on representation of old-growth structural attributes; and
2. assess values of individual old-growth attributes within stands as a guide to management practices for conserving and enhancing old-growth development.

This index should not be used as a rationale for managing stands to minimum attribute levels for old growth. To conserve biodiversity on the landscape, the full range of variability in all classes of old-growth development should be present.

Developing an Old-growth Index

Study Area

The study area includes all stands dominated by Douglas-fir on zonal ("/01") site series within all portions of the IDFdk3 and IDFdk4 biogeoclimatic variants in central British Columbia. These biogeoclimatic variants cover approximately 13 000 km^2 (Steen and Coupé 1997); zonal site series (IDFdk3/01 and IDFdk4/01) are estimated to cover at least 75% of this area. Zonal site series generally have medium-textured, deep soils developed in glacial till on gentle mid-slope or level sites and do not receive persistent seepage or have a near-surface water table (Steen and Coupé 1997).

Field Data Collection

The old-growth index was developed from data on 33 Douglas-fir stands (forest inventory polygons) representing a wide range of old-growth attribute development on IDFdk3 and IDFdk4 zonal sites. Twenty-nine polygons were randomly selected from all possible Douglas-fir–dominated polygons within six strata, consisting of three forest inventory age class groups (> 140 years, 81–140 years, ≤ 80 years) with two logging history categories (logged or unlogged) in each. Inventory age was used as a stratification criterion to ensure that the sample included stands of predominantly young as well as intermediate and old trees. Stands of predominantly old trees are most likely to have advanced old-growth attribute development. The 29 polygons included:

- 12 stands with an inventory age greater than 140 years (10 not logged and 2 logged);
- 12 stands with an inventory age of 81–140 years (10 not logged and 2 logged); and
- 5 stands with an inventory age of 80 years or less (3 not logged and 2 logged).

Two additional polygons were subjectively selected to represent our concept of typical old-growth stands and two others were subjectively selected to represent our concept of typical late–mature stands. Stands dominated by lodgepole pine (*Pinus contorta* var. *latifolia*) were not included in the sample, although most of the sample stands contained some pine.

Each polygon was field-examined before sampling to verify the ecosystem classification (i.e., IDFdk3/01 or IDFdk4/01). In addition, the sampling area within each polygon had to have a relatively uniform stand structure, a slope gradient of less than 30%, and an area of at least 12 ha. Polygons that did not meet selection criteria were replaced by new randomly selected polygons.

A transect of 10 sample plots at 75-m intervals was used to describe stand attributes. Each plot consisted of a variable-radius main plot (using a basal area factor 4 prism) and four satellite sample points located 25 m from the main plot centre. Two satellite points were located on the transect line and two on a bearing perpendicular to the transect line. All main-plot trees with a diameter at breast height (DBH; 1.3 m height) of 12.5 cm or greater were described by species, DBH, crown class (dominant, codominant, intermediate, suppressed), and wildlife tree class (Backhouse 1993). Height and age at breast height were recorded for 14 representative codominant Douglas-fir trees distributed along the transect.

The frequency of canopy gaps, dense regeneration thickets, and pinegrass (*Calamagrostis rubescens*) was recorded at the main plot centre and at each of the four additional sample points. A canopy gap was defined as an area greater than 25 m^2 without large stems (≥ 12.5 cm DBH). It could include any density of regeneration (i.e., stems < 12.5 cm DBH) and be caused by site features or tree fall. A dense regeneration thicket was defined as an area in which the foliage of small (< 12.5 cm DBH) tree stems covered more than 50% of the ground surface. A pinegrass vegetation area was defined as greater than 15% ground cover of pinegrass in a 1 m^2 plot centred on the sample point.

Coarse woody debris (CWD) of 7.5 cm or greater in diameter was sampled for volume and decay class along two 25-m transects extending from the centre of each main plot to a satellite sample point. Volume calculations followed those described by Van Wagner (1982). The proportions of five forest floor conditions (undisturbed/not mostly oxidized, undisturbed/mostly oxidized, compacted, scalped, and mixed with mineral soil) were assessed along each of the CWD transects.

Old-growth Gradient Definition

The 33 stands represent a range of old-growth attribute presence, from heavily disturbed stands with few or no old-growth attributes to stands with minimal evidence of stand-level disturbance. Because the stands are on equivalent sites (i.e., with similar climate, soils, slope, and moisture regime), stand structure and composition differences should reflect old-growth attribute development or disturbance rather than site differences. That is, in the absence of stand-level disturbances, all stands are expected to eventually develop a similar structure and composition.

Structural attributes recorded in the 33 stands were reduced to 22 attributes (Table 1) that are often used to distinguish old-growth forests (Kneeshaw and Burton 1998; Wells *et al.* 1998; Hale *et al.* 1999; Braumandl and Holt 2000; Trofymow *et al.* 2003; McElhinny *et al.* 2005; Hilbert and Wiensczyk 2007). We, therefore, considered these attributes as most important for guiding management practices to enhance old-growth development. Total basal area of all trees 57.5 cm DBH or greater is included in two attributes (BAO37 and BAO57). Similarly, density of all standing dead trees 37.5 cm DBH or greater (SNGAO37) and of hard standing dead trees (SNGHO37) both include hard snags because the SNGAO37 attribute takes in hard as well as intermediate and soft snags. Trees of 57.5 cm DBH or greater and hard snags greater than 37.5 cm DBH are double-counted because of their ecological significance in old-growth forests.

Using principal components analysis (Tabachnick and Fidell 2001), four attributes (FREQO37, STDDBH, GAPU2, REGO50) had a strong non-linear relationship to the main axis of total variation within the data set. These variables were transformed by exponential (FREQO37), logarithmic (STDDBH), or two linear (GAPU2, REGO50) functions to ensure that the relationship to the first principal component of variation was linear. No attempt was made to normalize the distribution of any measured variables.

The main stand structure gradients within the 33 stands and 22 attributes were identified by exploratory factor analyses. Factor analysis reduces a large number of correlated variables down to a small number of factors or underlying influences that are thought to "cause" the major correlations among the measured variables (Tabachnick and Fidell 2001). In this study, the first factor extracted by factor analysis was examined to determine whether it defines a gradient of old-growth stand structure development based on correlations among the 22 attributes. The first factor accounted for 54% of the shared variation within the data set compared to only 15% for the second factor.

Correlations (factor loadings) of measured stand structure attributes with the first factor (factor scores) indicate that the first factor defines a gradient of increasing old-growth development. Attributes having

TABLE 1. Stand structure attributes used to describe old-growth development. Primary attributes are used for old-growth index calculation and secondary attributes are used to qualify the old-growth index class. All tree species are included in the attributes.

Code	Description
PRIMARY ATTRIBUTES	
BA	Total basal area of all trees ≥ 12.5 cm DBH
BAO57	Total basal area of all trees ≥ 57.5 cm DBH
FREQO57	Percent of plots that contain at least one tree ≥ 57.5 cm DBH
BAO37	Total basal area of all trees ≥ 37.5 cm DBH
FREQO37	Percent of plots that contain at least one tree ≥ 37.5 cm DBH
DENU28	Density (stems per hectare) of trees 12.5–27.5 cm DBH
QMD	Quadratic mean diameter of tree boles ≥ 12.5 cm DBH
STDDBH	Standard deviation of DBH of all trees ≥ 12.5 cm DBH
PCODOM	Percent of stand basal area contributed by codominant trees
CL2O57	Density (stems per hectare) of class 2 wildlife trees ≥ 57.5 cm DBH
CL2O37	Density (stems per hectare) of class 2 wildlife trees ≥ 37.5 cm DBH
SNGAO57	Density (stems per hectare) of all standing dead trees ≥ 57.5 cm DBH
SNGAO37	Density (stems per hectare) of all standing dead trees ≥ 37.5 cm DBH
SNGHO57	Density (stems per hectare) of hard standing dead trees (wildlife tree classes 3 and 4) ≥ 57.5 cm DBH
SNGHO37	Density (stems per hectare) of hard standing dead trees (wildlife tree classes 3 and 4) ≥ 37.5 cm DBH
GAPU2	Percent of sample points in canopy gaps smaller than 0.2 ha[a]
GAPO2	Percent of sample points in canopy gaps larger than 0.2 ha[a]
SECONDARY ATTRIBUTES	
CWDHARD	Volume (m^3/ha) of coarse woody debris ≥ 7.5 cm in diameter in decay classes 1 and 2 (hard)
CWDINT	Volume (m^3/ha) of coarse woody debris ≥ 7.5 cm in diameter in decay class 3 (intermediate decay)
PPLBA	Percent of basal area in lodgepole pine trees
REGO50	Percent of sample points in a thicket of small trees (< 12.5 cm DBH) with ≥ 50% ground cover by needles (leaves)
VEGCALA	Percent of sample plots with > 15% ground cover of pinegrass (*Calamagrostis rubescens*)

[a] A frequency measure. A canopy gap is an area larger than 25 m^2 that has no stems ≥ 12.5 cm DBH. A gap may include any density of regeneration (stems < 12.5 cm DBH).

a strong positive correlation (> 0.60) to the first factor include (Table 2):

- basal area and frequency of large trees (BAO37, BAO57, FREQO37, FREQO57);
- mean diameter of trees (QMD)
- canopy structural complexity (STDDBH); and
- density of snags (SNGAO37, SNGAO57, SNGHO37).

Attributes that are negatively correlated to the first factor include:

- density of small trees (DENU28);
- percent of stand basal area in codominant trees (PCODOM);
- basal area of lodgepole pine (PPLBA); and
- proportion of stand area in large canopy gaps (GAPO2).

TABLE 2. Factor loadings of 22 attributes on first principal factor. Factor loadings are essentially correlations of the attribute with the first factor.

Attribute	Factor loading	Attribute	Factor loading
QMD	0.908	CL2O57	0.524
BAO37	0.894	SNGHO57	0.491
BAO57	0.890	REGO50	0.344
FREQO57	0.881	CWDINT	0.320
FREQO37	0.825	CWDHARD	0.206
SNGAO37	0.751	VEGCALA	0.028
SNGAO57	0.651	GAPU2	–0.120
STDDBH	0.618	GAPO2	–0.373
SNGHO37	0.610	PPLBA	–0.445
BA	0.594	PCODOM	–0.558
CL2O37	0.535	DENU28	–0.667

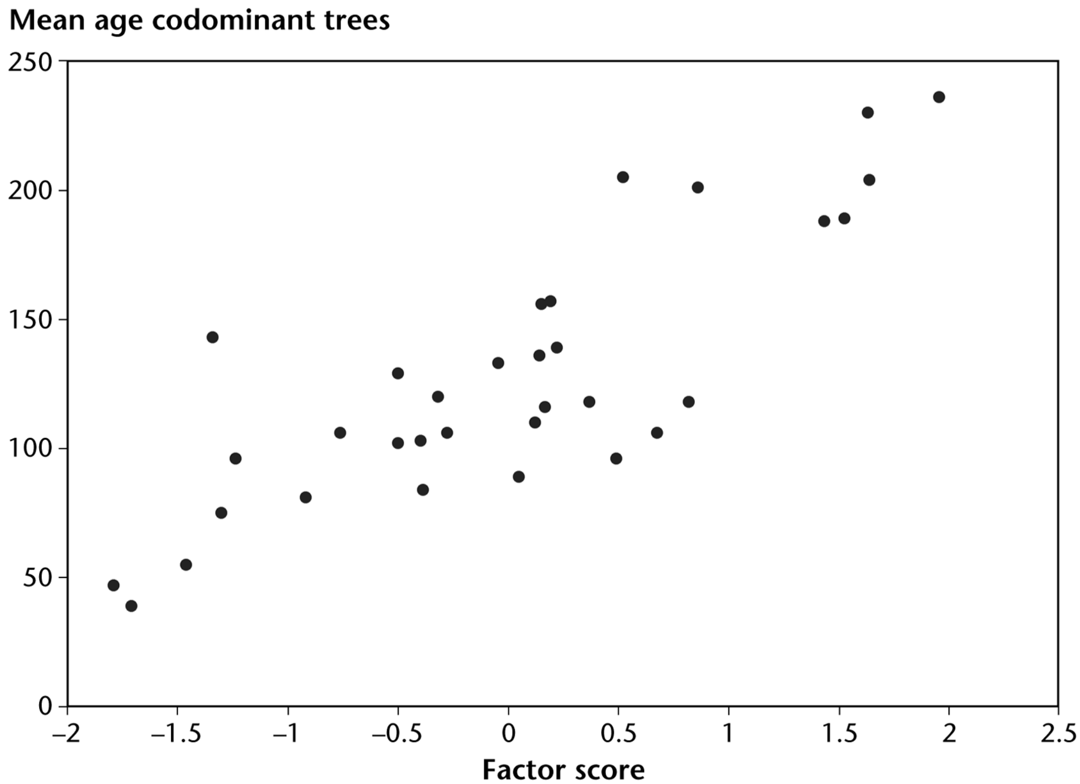

FIGURE 1. Relation of stand factor scores on first principal factor to mean age of codominant trees measured on-site. Stands with the most similar factor scores have the most similar set of structural attributes.

Decreasing percent basal area in codominant trees indicates increasing development of other tree layers. These correlations, both positive and negative, are all consistent with the definition of the first factor as a gradient of increasing "old growthness."

Correlation of the mean age of codominant trees, measured on-site in each stand, to stand scores on the first factor ($R^2 = 0.83$) supports the interpretation of the first factor as a gradient of increasing "old growthness" (Figure 1). Mean age was not included in the factor analyses. In comparison, inventory age classes of the sample polygons were less well correlated ($R^2 = 0.62$) to stand scores on the first factor.

Derivation of the Old-growth Index

Old-growth indexes were derived from the factor analysis results by weighting the standardized value of each selected attribute in a stand by its loading on the first factor and then summing the resulting products to get an overall index for the stand. In this way, each of the attributes contributes to the overall index for the stand in proportion to its correlation to the first factor. Standardized values were calculated by subtracting the mean value of the attribute in all stands from its value in the stand and dividing the result by the standard deviation of the attribute. A constant, specific to each attribute, was added to the product before summing so that values for all attributes were positive. Data transformations applied before the factor analyses were also applied to the data before calculating the old-growth index.

To avoid the use of unrepresented attribute values in the index calculation, the value of each attribute must be within the range of its values in the 33 sampled stands. In practice, this requirement should have a minimal effect because the allowed range of values for each attribute is large (Table 3), and extends from values characteristic of less-than-mature stands well into the range of values characteristic of old-growth stands. For example, the minimum and maximum allowed values span the range of seral stages and smaller or larger values would not alter classification of a stand as old growth, mature, or less-than-mature. Larger than maximum allowed values will seldom be encountered, whereas smaller than minimum allowed values may occasionally occur.

TABLE 3. Mean, standard deviation, and range of attribute values in each of four old-growth index classes. The range of values column includes the range across all stands within the data set and is the range of values allowed in index calculations.

		Old-growth index class (seral stage)			
Attribute	Range of values	Early seral	Mid-seral	Mature	Old growth
BA (m^3/ha)	9.1–45.0	14.6 (3.9, 11–19)[a]	25.7 (8.2, 18–44)	28.6 (7.7, 17–46)	38 (6.2, 29–45)
BAO57 (m^3/ha)	0–17	0.0 (0.0, all 0)	1.4 (1.6, 0–4)	6.3 (2.3, 3–10)	12.4 (3.4, 9–15)
FREQO57 (%)	0– 100	0 (0.0, all 0)	20 (19, 0–50)	70 (18, 50–90)	90 (10, 80–100)
BAO37 (m^3/ha)	0–30	0.7 (1.2, 0–2)	6.9 (4.3, 2–14)	13.2 (5.1, 6–24)	26 (3.9,20–30)
FREQO37 (%)	0–100	17 (21, 0–40)	61 (25, 20–90)	91 (10, 70–100)	100 (0, all 100)
DENU28 (stems per hectare)	150–850	523 (103, 422–627)	498 (127, 368–719)	362 (161, 189–865)	226 (39, 195–293)
QMD (cm)	15.5–40.0	18.3 (0.6, 18–19)	23.3 (3.1, 18–27)	27.5 (3.0, 22–33)	34.8 (1.9, 32–37)
STDDBH (cm)	5–28.1	7.0 (1.2, 6.1–8.4)	14.1 (4.0, 10.1–20.2)	22.3 (4.9, 11.4–28.1)	18.9 (2.6, 16.9–22.6)
PCODOM (%)	30–90	58 (14, 42–69)	52 (16, 31–78)	36 (8, 25–51)	35 (7, 27–44)
CL2O37 (stems per hectare)	0–10	0.0 (0.0, all 0)	1.0 (1.3, 0–3)	3.3 (2.8, 0–10)	6.6 (5.5, 0–15)
CL2O57 (stems per hectare)	0–6	0.0 (0.0, all 0)	0.4 (0.8, 0–2)	1.7 (1.6, 0–5)	3.2 (3.0, 0–6)
SNGAO37 (stems per hectare)	0–20	0.3 (0.6, 0–1)	1.3 (2.6, 0–7)	5.5 (6.1, 0–24)	21.6 (8.2, 12–30)
SNGAO57 (stems per hectare)	0–10	0.3 (0.6, 0–1)	0.7 (1.3, 0–3)	2.4 (2.1, 0–8)	6.8 (5.0, 1–12)
SNGHO37 (stems per hectare)	0–15	0.0 (0.0, all 0)	0.0 (0.0, all 0)	1.8 (2.8, 0–10)	7.8 (6.0, 0–15)
SNGHO57 (stems per hectare)	0–6	0.0 (0.0, all 0)	0.0 (0.0, all 0)	0.7 (1.5, 0–6)	2.0 (2.4, 0–6)
GAPU2 (%)	0–53	28.7 (24.0, 5–53)	17.7 (6.1, 8–26)	27.0 (15.9, 3–53)	29.0 (10.4, 16–40)
GAPO2 (%)	0–20	8.3 (10.4, 0–20)	0.0 (0.0, all 0)	0.8 (1.6, 0–5)	0.0 (0.0, all 0)
CWDHARD (m^3/ha)	0.1–25	7.3 (9.9, 0–19)	1.6 (2.9, 0–7)	6.2 (9.3, 0–37)	9.4 (9.5, 0–24)
CWDINT (m^3/ha)	0.1–80	31.6 (21.9, 9–52)	10.0 (10.9, 0–30)	20.3 (19.8, 0–80)	37.9 (17.8, 16–66)
PPLBA (%)	0–50	20.7 (13.3, 12–36)	25.7 (18.0, 4–49)	11.1 (14.5, 0–46)	3.8 (3.4, 0–8)
REGO50(%)	0–60	15.0 (23.9, 0–43)	18.2 (14.4, 5–35)	19.5 (16.7, 0–58)	27.0 (10.4, 13–40)
VEGCALA (%)	0–90	39.2 (12.8, 25–50)	40.4 (27.7, 3–70)	44.7 (26.0, 6–90)	38.1 (6.2, 33–48)
Mean age codominant trees	n/a	47 (8, 39–55)	103 (23, 75–120)	128 (34, 89–205)	209 (23, 188–230)
Mean age oldest 1/3 of trees	n/a	86 (19)	166 (38)	236 (58)	293 (22)
Mean age oldest tree	n/a	69 (11, 58–80)	147 (51, 108–231)	188 (45, 118–260)	296 (26, 264–319)
Mean DBH codominant trees	n/a	18 (2, 16–20)	28 (7, 18–38)	34 (6, 24–48)	40 (3, 36–43)
Douglas-fir basal area (%)	n/a	53 (30, 26–86)	73 (19, 46–96)	86 (16, 49–100)	95 (4, 90–100)
Deciduous basal area (%)	n/a	6 (8, 0–15)	1 (1, 0–3)	2 (5, 0–19)	0 (0, all 0)
Intact soil F layer (%)	n/a	61 (34, 40–100)	98 (4, 90–100)	95 (13, 55–100)	100 (0, all 100)
Thickness soil F layer (cm)	n/a	1.3 (0.2, 1.1–1.5)	1.5 (0.1, 1.3–1.5)	1.5 (0.3, 1.2–2.6)	1.5 (0.1, 1.4–1.7)

[a] Values presented as mean (standard deviation, range of attribute values).

Forms of Old-growth Index

To accommodate different levels of data availability, three forms of the old-growth index were developed using different subsets of the 22 attributes. These three forms differ only in the number of included attributes and the factor loadings for each attribute. Factor loadings differ because each of the indexes was developed from a unique factor analysis using only the attributes included in the index.

To develop the three forms, the 22 attributes were first separated into two groups—17 primary attributes and 5 secondary attributes (Table 1). The 17 primary attributes are those most strongly correlated to the first factor and are therefore considered the most useful for distinguishing old-growth stands. The five secondary attributes are those with a lower correlation to the first factor, are more variable within old stands, and are therefore considered less important for distinguishing old-growth stands. These attributes are not included in any of the old-growth indexes, but are used in subsequent qualifiers of old-growth development.

Attributes identified as secondary include coarse woody debris volumes (CWDHARD and CWDINT), extent of dense regeneration thickets (REGO50), frequency of pinegrass vegetation (VEGCALA), and proportion of stand basal area in lodgepole pine (PPLBA). Although coarse woody debris volume is often considered an indicator of old-growth stands and is an important attribute for managing biodiversity (Lofroth 1998; Trofymow *et al.* 2003), old Douglas-fir forests in the northern IDFdk have highly variable volumes of woody debris, depending on the frequency and intensity of past ground fires and tree mortality. This variability suggests that coarse woody debris should not be used to identify old growth in the northern IDFdk.

Extensive thickets of high-density small stems (high REGO50 value) would be considered an indicator of an early-seral stage in many ecosystems; however, in the IDFdk, the extent of dense thickets is highly variable within and between stands that would otherwise be considered old growth. This variability seems related to the severity and spatial extent of previous fires and other factors affecting seedling establishment. The frequency of pinegrass vegetation is negatively related to the density of small stems and varies for the same reasons. The proportion of stand basal area in lodgepole pine was not included because of its low and variable density in the sampled stands and its resulting low correlation to the first factor.

The three forms of the index are termed the "Primary," "Modified," and "Reduced." The Primary Index uses all 17 primary attributes. Because it is based on the largest number of attributes, it is the preferred index when adequate data is available. Primary indices for the 33 stands were strongly correlated ($R^2 = 0.991$) to scores using all 22 attributes.

The Modified Index includes all but three of the attributes (PCODOM, GAPO2, GAPU2) included in the Primary Index. These attributes may not be easily measured in operational surveys and may be sensitive to small differences in field sampling methodology. Old-growth indices for the 33 stands calculated with this index were strongly correlated ($R^2 = 0.986$) to scores using all 22 attributes.

The Reduced Index omits five attributes contained in the Primary Index. These include the three attributes (PCODOM, GAPU2, GAPO2) omitted from the Modified index and two attributes that describe the frequency of large trees (FREQO37 AND FREQO57). Frequency attributes were deleted to allow greater flexibility in sampling methods (i.e., fewer plots and a sampling prism with basal area factor other than 4). Old-growth indices calculated with this index were moderately well correlated ($R^2 = 0.901$) to scores based on all 22 attributes.

Old-growth Index Classes

The old-growth index value for a stand describes its position on a gradient of increasing old-growth attribute development, or degree of "old growthness." In practice, however, it is often useful to describe stands by classes of old growthness. Consequently, when using the Primary Index, the range of index values for the 33 stands was broken into four segments to denote old growth plus three structural classes representing lesser degrees of old-growth attribute development. These four old-growth index classes were termed "old growth," "mature," "mid-seral," and "early seral," and are similar to the four seral stages identified by the *Biodiversity Guidebook* (B.C. Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995). The classes do not necessarily represent a temporal sequence (as in ecological succession), but simply reflect levels of old-growth attribute representation.

First, the four classes were provisionally identified as equal segments of the range of Primary Index values from 0 to 34 (i.e., 0–8.5, 8.6–17, 17.1–25.5, 25.6–34). Breaking the range of values into four equal segments resulted in 3 stands in provisional class 1, 8 stands in provisional class 2, 15 stands in provisional class 3, and 7 stands in provisional class 4. Provisional class 4 (old growth) included the two stands selected to represent our concept of old growth and one of the two stands selected to represent our concept of late–mature stand structure.

Next, each stand was evaluated for attribute consistency with other stands in its provisional class and with our professional judgement of what structures constitute mature and old-growth forests in the IDFdk3 and IDFdk4. This evaluation focussed on:

- stands whose index values were at the high or low end of the range for the provisional class; and
- stands that had two or more attributes with outlier values within the provisional class.

These stands were subjectively compared for similarity to other stands in the provisional class and in the adjacent "younger" or "older" provisional group. The evaluation considered all primary and secondary attributes and mean age of codominant trees.

Two stands in provisional class 2 with the highest index values (16.4 and 16.9) were moved to class 3 (mature), based on high stand basal area, representation of very large (> 57.5 cm DBH) stems, density of wildlife trees and snags, and diversity of tree sizes. In addition, two stands in provisional class 4 with the lowest index values (26.2 and 26.3) were moved to class 3 based on low basal area of large (> 37.5 DBH) and very large (> 57.5 cm DBH) trees and high densities of small (< 27.5 cm DBH) trees. One of these two stands had been subjectively selected before sampling as an analysis marker of our concept of typical late–mature stand structure. The reassignment of these four stands resulted in 5, 19, 6, and 3 stands in old-growth, mature, mid-seral, and early-seral classes, respectively.

Table 3 shows a comparison of the means and ranges of attribute values in the resulting four classes. Class 4 (old growth) is clearly distinguished from class 3 by high basal area and frequency of very large trees (> 57.5 cm DBH), low density of small trees (≤ 27.5 cm DBH), high quadratic mean diameter of trees, and high basal area of snags and class 2 wildlife trees. Class 4 has the greatest mean age of codominant trees (209 years) and the greatest mean age of the oldest codominant tree (296 years) in each stand. Stands in class 3 are consistent with our concept of mature IDFdk stand structure. They are distinguished from class 2 by a greater frequency of very large trees (> 57.5 cm DBH), greater basal area of large trees (> 37.5 cm DBH), greater variability (standard deviation) of tree diameters, and greater basal area of snags and class 2 wildlife trees. Class 2, or mid-seral, is distinguished from class 1 (early seral), by stand basal area greater than 15 m^2/ha, occasional presence of very large trees (> 57.5 cm DBH), larger quadratic mean diameter of trees, greater variation (standard deviation) of tree diameters, and absence of large canopy gaps (GAPO2). Class 1 has the youngest mean age of codominant trees (47 years) and youngest mean age of the oldest codominant tree (69 years) in each stand.

The regroupings resulted in a redefinition of the index value ranges for the four classes using the Primary Index (Table 4). For the Modified and Reduced indexes, the index value ranges in each class were determined by maintaining the stand classification established with the Primary Index. This was a straightforward procedure as the order of stands did not change between the Primary and other forms of the index. The boundaries of the old-growth index classes for the Modified and Reduced indexes are listed in Table 4. Because fewer attributes' values are summed, the index value ranges within each class decrease from the Primary to the Modified and Reduced indexes.

TABLE 4. Range of index values for each old-growth index class (seral stage) and form of the index

	Form of index		
Index class	**Primary**	**Modified**	**Reduced**
Early seral	0–8.0	0–4.0	0–3.5
Mid-seral	8.1–16.0	4.1–11.5	3.6–8.5
Mature	16.1–27.0	11.6–22.0	8.6–17.0
Old growth	> 27.0	> 22.0	> 17.0

Old-growth Index Class Qualifiers

Each of the four old-growth index classes is represented on the landscape by many variations in stand structure and composition; therefore, an index value may be arrived at through various combinations of attributes. To more fully describe this variation, we developed qualifiers of the four index classes. These can help practitioners to recognize structural attribute variation and to guide management practices that enhance the old-growth development of each unique stand. Qualifiers describe the old-growthness of each individual attribute just as the old-growth index describes the overall old-growthness of the stand.

To derive these qualifiers, each attribute in a stand is assigned a score by comparing its value in the stand to its mean value in each of the four old-growth index classes. Thus, the score is based on a comparison of the class of the stand and the class with the most similar mean for the attribute. For example, a stand may have an overall classification of mature; however, it may have one or more attributes characteristic of old growth, mid-seral, or early-seral structure. Procedures for assigning qualifier scores are described more fully below.

Applying the Index

Data Collection

Although only primary attributes are required to determine a stand's old-growth index, the addition of secondary attributes can provide for more comprehensive structural descriptions and can guide management practices to maintain or enhance old-growth attributes. Full use of the old-growth index, including the qualifiers, requires data on all primary and secondary attributes listed in Table 1.

In general, the index should be applied only to stands greater than 12 ha. At a minimum, stands should contain 10 sample plots spaced 50 m apart and 75 m from stand edges. Plots may be part of a standard sampling procedure, such as a timber cruise, or an old-growth assessment survey with systematically or randomly located plots.

For the Primary and Modified indexes, tree data must be collected in variable radius plots using a basal area factor 4 prism. Because the frequency of plots containing large trees (FREQO37 and FREQO57) depends on plot size, the Primary and Modified indexes will not be valid if a prism with any other basal area factor is used. Fifteen of the 17 primary attributes (BA, BAO37, BAO57, CL2O37, CL2O57, DENU28, FREQO37, FREQO57, PCODOM, QMD, SNGAO37, SNGAO57, SNGHO37, SNGHO57, and STDDBH) can be sampled in variable radius plots using standard forest survey procedures. Frequency of canopy gaps (GAPO2 and GAPU2) can be sampled by recording the presence and estimated size of canopy gaps at as many sample points as possible, such as at the main plot centres and the satellite sample points of this study. We recommend a minimum of 50 sample points.

Of the secondary attributes, percent of stand basal area in lodgepole pine trees (PPLBA) can be sampled using variable radius plots. Coarse woody debris (CWDHARD and CWDINT) is best sampled by a line intercept method, with lines running along and perpendicular to the transect line between plots. We recommend using at least 200 m of intercept to sample coarse woody debris. (See Van Wagner [1982] for a description of line intercept procedures.) The frequency of regeneration thickets with more than 50% needle/leaf ground cover (REGO50) and the frequency of pinegrass vegetation (VEGCALA) can both be determined at the same sample points used to assess canopy gap frequency.

Determining the Index Class and Index Class Qualifier

A Microsoft Excel spreadsheet that calculates all three old-growth indexes from stand data is available at *http://www.forrex.org/publications/other/IDF_old-growth_index_calculator.xls.* Here we provide an example of an index calculation using the Primary Index. In this example, mean stand data (Table 5) from 10 plots (10 main plots and 40 additional sample points) were entered into the first column of the spreadsheet. The spreadsheet does all subsequent calculations without further user input. As none of the entered values are outside the range of values in our study, none were converted within the spreadsheet.

The spreadsheet conducts any needed data transformations and then standardizes each data value using the means and standard deviations of values in this study (Table 5). Standardized values are

TABLE 5. Example calculation of old-growth index using Primary Index

Attribute	Field data	Transformed data	Data standardization	Standardized data	Weighted score	Constant	Final score
BA	18.8	18.8	$X'= (X - 28.167)/9.166$	−1.022	−0.62	1.26	0.64
BAO57	4	4	$X' = (X - 5.636)/4.365$	−0.375	−0.33	1.15	0.82
FREQO57	60	60	$X' = (X - 56.027)/33.408$	1.316	0.11	1.50	1.61
BAO37	6	6	$X' = (X - 12.667)/8.256$	−0.807	−0.72	1.37	0.65
FREQO37	80	6.9	$X' = (X - 8.152)/3.693$	−0.345	−0.29	1.66	1.37
DENU28	328	328	$X' = (X - 385.273)/162.493$	−0.352	0.23	1.85	2.08
QMD	25.5	25.5	$X' = (X - 26.879)/5.165$	−0.267	−0.24	2.01	1.76
STDDBH	27.2	10.6	$X' = (X - 8.004)/2.378$	1.084	0.69	1.91	2.60
PCODOM	38	38	$X' = (X - 41.364)/13.071$	−0.257	0.15	2.11	2.25
CL2O37	3	3	$X' = (X - 3.03)/3.486$	−0.009	0.00	0.48	0.47
CL2O57	3	3	$X' = (X - 1.515)/1.856$	0.800	0.42	0.42	0.84
SNGAO37	3	3	$X' = (X - 6.576)/8.675$	−0.412	−0.31	0.57	0.26
SNGAO57	3	3	$X' = (X - 2.515)/3.134$	0.155	0.10	0.50	0.60
SNGHO37	2	2	$X' = (X - 2.152)/3.882$	−0.039	−0.02	0.34	0.32
SNGHO57	2	2	$X' = (X - 0.697)/1.51$	0.863	0.41	0.22	0.64
GAPU2	38	11.5	$X' = (X - 16.434)/3.008$	−1.654	0.20	0.47	0.27
GAPO2	0	0	$X' = (X - 1.182)/3.670$	−0.322	0.13	2.01	2.13
						Sum =	*19.3*

then multiplied in the spreadsheet by factor loadings to determine the weighted score for each attribute (Table 5). A constant is added to the weighted scores and all resulting scores are summed to determine the old-growth index for the stand. When compared to the values in Table 4, the resulting index value of 19.3 (Table 5) indicates that the stand's old-growth index class is "mature."

Qualifiers of the old-growth index class are determined manually for each attribute. Table 6 shows how index class qualifiers are determined for the same stand used in the example above. A score (–2, –1, 0, +1, or +2) is determined for each attribute by comparing the value of the attribute in this stand to mean values for the same attribute in each of the index classes. The score is based on the difference between the index class of the stand (mature) and the class with the most similar mean value for the attribute. Table 7 provides a range of attribute values around each mean. These are used to determine which index class has a mean value most similar to that of the stand in our example. The range of attribute values between means for adjacent index classes is divided between the two classes according to the relative size of their attribute value standard deviations. In the example stand (Table 6), tree basal area is given a score of –1 because this attribute value (18.8 m^2/ha) was within the range of values (18.2–27.1 m^2/ha) for mid-seral, which is one class less than the class of the example stand (mature). Similarly, density of very large declining trees (CL2O57) is given a score of +1 because this value (3 stems per hectare) is within the range of values (> 2.2 stems per

TABLE 6. Example determination of old-growth index class qualifiers

Attribute category/attribute	Field data	Qualifier score: Attribute	Qualifier score: Attribute category	Qualifier
Site Occupancy			**–1**	**Low**
BA (m^2/ha)	18.8	–1		
Very Large Live Trees			**0**	**Equivalent**
BAO57 (m^2/ha)	4	0		
FREQO57 (%)	60	0		
Large Live Trees			**–1**	**Low**
BAO37 (m^2/ha)	6	–1		
FREQO37 (%)	80	–1		
Small Live Trees			**0**	**Equivalent**
DENU28 (stems per hectare)	328	0		
Mean Tree Diameter			**0**	**Equivalent**
QMD (cm)	25.5	0		
Canopy Structure			**0**	**Equivalent**
STDDBH	27.2	0		
PCODOM (%)	38	0		
Declining Trees			**+0.5**	**Equivalent–High**
CL2O37 (stems per hectare)	3	0		
CL2O57 (stems per hectare)	3	+1		
Total Snags			**0**	**Equivalent**
SNGAO57 (stems per hectare)	3	0		
SNGAO37 (stems per hectare)	3	0		
Hard Snags			**+0.5**	**Equivalent–High**
SNGHO37 (stems per hectare)	2	0		
SNGHO57 (stems per hectare)	2	+1		
Coarse Woody Debris			**0**	**Equivalent**
CWDHARD (m^3/ha)	18.6	+1		
CWDINT (m^3/ha)	6.3	–1		
Lodgepole Pine			**–1**	**Low**
PPLBA (%)	19	–1		

TABLE 7. Range of attribute values used to determine the index class that has a mean most similar to the value of an attribute in a stand. The ranges are values around the mean of an attribute in each index class. Boundaries between classes were proportioned by their standard deviations.

	Index class (seral stage)			
Attribute group/variable	**Early seral**	**Mid-seral**	**Mature**	**Old growth**
Site Occupancy				
BA (m^2/ha)	< 18.2	18.2–27.1	27.2–33.7	> 33.7
Very Large Live Trees				
BAO57 (m^2/ha)	0	0.1–3.3	3.4–8.7	> 8.7
FREQO57 (%)	0	0.1–45.6	45.7–82.7	> 82.7
Large Live Trees				
BAO37 (m^2/ha)	< 2.1	2.1–9.7	9.8–20.4	> 20.4
FREQO37 (%)	< 37.0	37.0–82.4	82.5–99.0	> 99.0
Small Live Trees				
DENU28 (stems per hectare)	> 511.8	438.3–511.8	252.3–438.2	< 252.3
Mean Tree Diameter				
QMD (cm)	< 19.1	19.1–25.4	25.4–31.9	> 31.9
Canopy Structure				
STDDBH (cm)	< 8.6	8.6–17.7	> 17.7	> 17.7
PCODOM (%)	> 55.2	41.2–55.2	35.5–41.3	< 35.5
Declining Trees				
CL2O37 (stems per hectare)	0	0.1–1.7	1.8–4.3	> 4.3
CL2O57 (stems per hectare)	0	0.1–0.8	0.9–2.2	> 2.2
Total Snags				
SNGAO57 (stems per hectare)	< 0.4	0.4–1.3	1.4–3.7	> 3.7
SNGAO37 (stems per hectare)	< 0.5	0.5–2.5	2.6–12.3	> 12.3
Hard Snags				
SNGHO37 (stems per hectare)	0	0	0.1–3.7	> 3.7
SNGHO57 (stems per hectare)	0	0	0.1–1.1	> 1.1
Coarse Woody Debris				
CWDHARD (m^3/ha)	—	< 2.7	2.7–7.7	> 7.7
CWDINT (m^3/ha	—	< 13.6	13.6–29.5	> 29.5
Lodgepole Pine				
PPLBA (%)	—	> 17.6	5.2–17.6	< 5.2

hectare) about the mean for old growth, which is one class greater than that of the stand.

Index class qualifiers are then determined for the 11 categories of attributes (Table 6). Qualifiers for categories with two or more attributes are averages for values of attributes within the category. For example, the coarse woody debris category (includes CWDHARD and CWDINT) is given a score of 0, which is the average of individual scores for CWDHARD (+1) and CWDINT (–1). For categories with only one attribute, the category score is the attribute score. Finally, numeric scores for each attribute and attribute category are expressed as very low (< –1.5), low (–1.4 to –0.5), equivalent (–0.4 to +0.5), high (+0.6 to +1.5), or very high (> +1.5).

Based on all scores, the stand described in Tables 5 and 6 is assessed as mature with low site occupancy (BA;

most similar to mid-seral), low representation of large live trees (BAO37 and FREQO37; most similar to mid-seral), and high representation (low score) of lodgepole pine (density of pine most similar to mid-seral). Development towards old growth could be enhanced by harvesting small trees (especially pine) and maintaining large trees (> 37.5 cm DBH). Hard CWD should be conserved because it is the source of coarse woody debris with intermediate levels of decay, which had a low score in this stand. Because the index for the stand was near the low end of the range for the mature class, a relatively long time would likely be required for the stand to reach old growth.

Discussion

Although biodiversity conservation is a widely acknowledged objective of forest management in North America, assessing the total number of species on forested landscapes and monitoring the effects of forest management practices on this number is clearly beyond the scope of practical resource management. Consequently, biodiversity conservation strategies commonly use surrogates to describe and monitor biodiversity (McElhinny *et al.* 2005). Surrogates most commonly used at the stand scale are the presence, abundance, and distribution of structural attributes, such as large trees, canopy gaps, and dead trees (Kneeshaw and Burton 1998; Wells *et al.* 1998; Trofymow *et al.* 2003; Hilbert and Wiensczyk 2007).

In British Columbia, surrogates commonly used to assess biodiversity conservation values at the landscape scale are seral stages. This recognizes that all seral stages, from early seral to old growth, should be represented on the landscape. In the absence of disturbances, structural development progresses from small trees and relatively simple structures to increasingly complex structures with multiple canopy layers, a large diversity of trees sizes, a diverse understorey, and the presence of standing and fallen dead wood.

However, in forests that experience repeated low- to mixed-severity disturbances (including partial harvesting) stand structural development does not proceed in a predictable way. In these forest types, successional development is interrupted and altered to various degrees in response to partial disturbance frequency and severity. In these stands, a more direct measurement than stand age is needed to predict old-growth structural development.

The four old-growth index classes (old growth, mature, mid-seral, early seral) are, in our opinion, meaningful and useful predictors of stand structure types pertinent to biodiversity conservation. Although these classes are not strictly synonymous with the successional stages that would develop in a linear direction following stand initiation, they meaningfully represent increasing levels of old-growth attribute representation in both naturally disturbed and managed (logged) stands. For biodiversity management, we believe that these old-growth index classes can be treated as equivalent to seral stages.

Many of the sample stands used to develop the index had been logged, often more than once. These stands were included in the sample because we believe that the index should reflect the effects of both natural disturbances and recent human-related disturbances such as logging. Tree cutting has occurred in most stands of the IDFdk3 and IDFdk4. Although industrial disturbances typically have different effects on stand structure than do many natural disturbances (e.g., wildfire), both types of disturbance are part of the current regime in IDFdk forests.

Moss and Farnden *et al.* recently defined stand structure types for the study area (Moss 2003, 2004; Farnden *et al.* 2003). These definitions are based on the cumulative number of trees per hectare, starting with the largest tree in each stand. Seventeen types are described, ranging from "even-aged" stands with a narrow range of diameters to "uneven-aged" stands with a broad range of diameters. Although these types can be of significant value for designing timber management practices and some of the definitions are predominantly related to old growth, we believe they are less appropriate for assessing biodiversity attribute values than the types described in this study.

An assumption of the old-growth index described here is that the means and standard deviations of attribute values in the sample stands are similar to the means and standard deviations of these attributes in the entire population of Douglas-fir stands within the study area. Because most stands in the sample were selected by a stratified random approach, confidence in the validity of the assumptions is increased. The four subjectively selected stands in the sample ensure that stands representing advanced stages of old-growth development (old growth and older mature) were included in the sample. This was necessary, in part, because old growth and late–mature unlogged stands are currently uncommon in the IDFdk3 and IDFdk4, even though they likely dominated the pre-industrial landscape (Dawson 1998).

We believe that the stands included in this study reasonably represent the range of attributes currently present in mature and old-growth stands in the IDFdk3 and IDFdk4. They do not, however, adequately represent severely disturbed stands with few old-growth legacies. The sample size of such stands was small (five). Therefore, we recommend that the index is used primarily to distinguish old growth from mature stands and mature from younger-than-mature stands (mid-seral and early seral).

The old-growth index and the index boundaries that we subjectively selected to define index classes (seral stages) are based primarily on expert opinion and thus quantify our best professional judgement about the attributes necessary for a stand to be considered old growth or mature. As professional judgement is a characteristic of nearly all old-growth indices (Wells *et al.* 1998), this index provides a consistent and common approach for forest managers.

Based on our considerable experience in IDFdk3 and IDFdk4 forests, we believe that the index meaningfully and correctly identifies old growth and mature Douglas-fir forests within these biogeoclimatic variants. However, the index has been applied to only a relatively small number of stands beyond those included in the sample. We encourage further testing and evaluation of the index.

The sample stands included in this study do not fully represent the range of old-growth forests on the pre-industrial landscape. Before European contact, fires were much more frequent than at present and had a significant effect on stand structure (Iverson *et al.* 2002; Daniels 2005). For example, stands with low densities of small stems were likely more common than represented in our sample, and coarse woody debris volumes may have been smaller due to consumption by wildfire. As a result, we do not recommend using the old-growth index to guide or evaluate ecosystem restoration objectives. However, the index would not substantially penalize restoration attempts because index values increase with decreasing densities of small (< 27.5 cm DBH) stems and coarse woody debris volume is not included in the index determination. Intermediate-sized stems (27.5–37.5 cm DBH), which may also have increased in number following European settlement, are not included in the index. Total stand basal area, which is a key attribute in the index, has likely increased following European settlement.

We suggest that development of some old-growth attributes can be accelerated by focussed management of stand structural attributes, a conclusion consistent with that of others (e.g., Hansen *et al.* 1991; Kneeshaw and Burton 1997; Burton *et al.* 1999). This can be accomplished by using management practices that enhance those attributes whose development lags behind the overall attribute development of the stand and by ensuring that other attributes are not depleted. For example, old-growth development of a mature stand with high density of small stems and low density of large stems can be accelerated by thinning of small stems, which allows more rapid growth of larger stems. Other management practices may include creating small canopy gaps, increasing retention of large trees, maintaining or increasing the number of standing dead trees, minimizing soil disturbance, and increasing the volume of coarse woody debris.

As professional judgement is a characteristic of nearly all old-growth indices, this index provides a consistent and common approach for forest managers.

Some authors (e.g., Burton *et al.* 1999) suggest that certain old-growth stands can be partially harvested and still retain their old-growth character, as long as threshold values of selected attributes are maintained. Burton *et al.* (1999) cautioned that this is possible only if timber is removed without damaging other old-growth attributes such as soils, which may or may not have defined threshold levels. They also cautioned that recommended threshold levels should be tested to determine whether they are sufficient to maintain old-growth function. For these and other reasons, we have chosen not to define threshold values for individual old-growth attributes and do not suggest that large trees can be harvested while maintaining the old-growth character of a stand. Widespread use of the index to design industrial harvesting of old-growth stands to minimum attribute levels would reduce landscape-level diversity of old-growth stands and possibly have significant effects on attributes not included in the index. Conversely, some low-impact practices, such as hand-thinning of small stems with negligible ground disturbance, would maintain or more quickly enhance the old-growth character of a stand.

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Test Your Knowledge . . .

An old-growth index for Douglas-fir stands in portions of the Interior Douglas-fir zone, central British Columbia

How well can you recall some of the main messages in the preceding Research Report? Test your knowledge by answering the following questions. Answers are at the bottom of the page.

1. Why are old-growth definitions that are based on direct measurement of structural attributes, rather than on inventory age, needed for Douglas-fir forests of the IDFdk3 and IDFdk4?

2. Which of the following structural attributes is/are not used to calculate at least one form of the old-growth index?
   a) Total basal area of trees >12.5 cm DBH
   b Density of standing dead trees > 57 cm DBH
   c) Volume of coarse woody debris
   d Standard deviation of tree diameters at breast height
   e) Mean age of codominant trees
   f) Percent of total stand basal area contributed by codominant trees

3. What is the main purpose of the old-growth index class qualifiers?

Answers

1. Inventory age does not reliably predict the presence of old-growth attributes for forests in which successional development is interrupted and altered by frequent low- to mixed-severity partial disturbances, and structural legacies from previous stands are often present.

2. C and E

3. To guide management prescriptions that will maintain or enhance development of old-growth attributes.