Research Report

B.C. Journal of Ecosystems and Management

Using forest structural diversity to inventory habitat diversity of forest-dwelling wildlife in the West Kootenay region of British Columbia

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Abstract

Forest planners in British Columbia are being asked to consider wildlife species diversity in forest development plans. Forest ecosystem inventories currently used in British Columbia are inappropriate or inadequate as tools for land management planning because they only document forest composition (Vegetation Resources Inventory) or identify plant communities (Terrestrial Ecosystem Mapping). To assist in the effort to obtain information about a site's potential forest-dwelling wildlife species diversity, we developed a method of using forest structure to identify and evaluate habitat quality for multiple species of vertebrates. Using aerial photos, we delineated six classes of forest structure that have been identified by other researchers as important wildlife habitats. We selected five structural attributes of forest stands—vertical structure (canopy complexity), horizontal structure (forest patchiness), coarse woody debris density, litter and duff layer depth, and tree size—to be measured in the field, and we applied the method in three study areas in southeastern British Columbia. We compared abundance of structural features between structural classes to determine whether the classes were indeed unique. Old forests were found to be more structurally complex than younger forests, and forested and riparian sites were more structurally complex than non-forested and upland sites. We then used this data to index structural diversity within a study area to allow stands to be compared. We suggest that our method can be used by biologists and land managers to guide the conservation of forest-dwelling wildlife species.

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Volume 2, Number 2, 2002
http://www.forrex.org/jem/2002/vol2/no2/art1.pdf

Introduction

Conservation of biodiversity has become a major concern of land managers in North America. However, many regard biodiversity as too broad or vague a concept to be addressed or applied in land management situations (Noss 1990). Research in the Pacific Northwest has indicated that using a coarse-filter approach to habitat conservation that is based on individual species does not necessarily ensure the viability of all species (Marcot *et al.* 1994). The work of Thomas *et al.* (1993) showed that the conservation of spotted owl habitat did not provide for all the needs of other species that reside in similar habitats. Wildlife species diversity may be better conserved if we base our approach on overall habitat conservation (Noss 1990). Although inferences between habitat and species abundance are influenced by the type of habitat features measured, habitat approaches to the management of wildlife species are attractive because of the ease with which some habitat attributes can be measured. Indeed, in British Columbia, one of the main assumptions of current forest-management guidelines is that biological diversity can be maintained by maintaining habitat diversity (BC Ministry of Forests and BC Ministry of Environment 1995). Thus, approaches based on habitat seem to be realistic for managing for multiple species (Hansen *et al.* 1995).

> *Given that structural features provide critical habitat components for forest-dwelling wildlife species, it follows that presence or absence of these species may be positively correlated with the presence or absence of such structural features.*

In British Columbia, forest companies must manage for many different species—including grizzly bears, caribou, and other rare and threatened species—as well as for biodiversity. However, data about both species and habitat is lacking because current inventories provide only gross information about forest composition (Vegetation Resources Inventory) or merely identify plant communities (Terrestrial Ecosystem Mapping). Therefore, forest companies and government agencies need information that can be used to help manage habitat needs for many species. Ideally, this information should be general enough to allow biologists and managers to make decisions, at the stand level and higher, regarding potential diversity of forest-dwelling wildlife species.

Franklin *et al.* (1981) and Noss (1990) proposed monitoring three components of habitat diversity: composition, function, and structure. There appears to be little relationship between plant species composition and vertebrate species richness (Short and Williamson 1986; Currie 1991), and function is often difficult to measure (Franklin and Spies 1991). Several researchers have hypothesized that vertebrate habitat diversity is associated with forest structure (Urban and Smith 1989; Short and Williamson 1986; Hansen *et al.* 1995). In addition, it may be that structural characteristics, not plant species composition, are the primary determinants of avian community diversity (MacArthur and MacArthur 1961). Given that structural features provide critical habitat components for forest-dwelling wildlife species, it follows that presence or absence of these species may be positively correlated with the presence or absence of such structural features.

Our objectives were to develop a method to map forest structural classes, to inventory selected habitat features, to determine whether the structural classes we identified were indeed unique, and to develop a ranking system based on abundance of the measured structural features for use in planning forest management activities. In this paper we present and discuss our method, illustrate differences between structural classes, and present a ranking system for sites in terms of abundance of structural features. This method can be used to determine which stands may have a high diversity of vertebrate species, and can guide land managers in planning for the conservation of forest-dwelling wildlife species.

Study Areas

In 1997–98 we worked in three areas of the West Kootenay region (Figure 1), in southeastern British Columbia. The Grohman Creek study area (11 036 ha) is north of Nelson (49° 33’ N, 117° 21’ W). The Sheppard Creek study area (6307 ha) is south of Trail and Rossland just north of the British Columbia/Washington border (49° 06’ N, 117° 44’ W). The Perry Ridge study area (16 000 ha) is about 40 km northwest

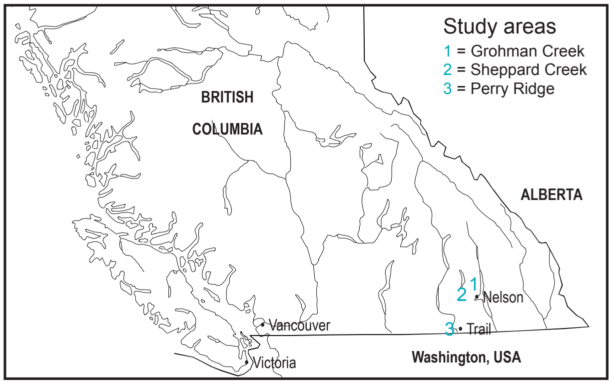

FIGURE 1. Location of the three study areas in southeastern British Columbia.

of Nelson. All three areas have a long history of timber harvesting, which extends to recent times, and more harvesting was scheduled to take place over the subsequent five years (i.e., 1998–2002).

All three areas are characterized by mountainous topography. Three biogeoclimatic zones predominate: the Interior Cedar–Hemlock zone (ICH), the Engelmann Spruce–Subalpine Fir zone (ESSF), and the Alpine Tundra zone (AT) (Braumandl and Curran 1992). Annual precipitation ranges from 50 to 100 cm, a large portion of which is snow. Dominant tree species in the ICH zone include western hemlock (*Tsuga heterophylla*) and western redcedar (*Thuja plicata*) in the wetter areas, and Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta*) on drier sites. In the ESSF zone, tree species include hybrid spruce (*Picea glauca x engelmannii*), subalpine fir *(Abies lasiocarpa)*, and lodgepole pine. The AT zone was predominantly non-forested, but contained scattered, open stands of subalpine fir.

Methods

Aerial Photo Analysis

We stratified each study area based on structural differences among stands; structural classes were based largely on stand age. We delineated six structural classes on aerial photos—based mainly on differences in tone and texture—that have been identified by other researchers as important wildlife habitats (Thomas 1979; Meslow *et al.* 1981; Hoover and Wills 1984; Hall *et al.* 1985; Cooperrider *et al.* 1986; Thomas *et al.* 1988). Aerial photos were at the scale of 1:20 000 or larger and were taken within the last 10 years.

The six forest structural classes were designated as:

- Old Forest—Old stands that exhibit distinctly different structural characteristics than younger stands. We did not label this class "old growth" because Old Forest is much broader than many current definitions of old growth. We used the following six stand attributes to identify Old Forest on aerial photos: presence of trees >140 years (or >120 years in Douglas-fir dominated stands), distinctive large crowns in the upper canopy, spatial patchiness, low densities of large trees, and greater vertical complexity compared to younger age classes.
- Mature Forest—Contains somewhat less vertical complexity and somewhat fewer canopy gaps than Old Forest. Tree density varies among stands.
- Immature Forest—Contains significantly less vertical complexity and significantly fewer canopy gaps than Old Forest. Tree density varies among stands.
- Early Seral Forest—Recently clearcut areas. Characterized by a lack of overstorey cover and dominance by conifer regeneration, shrubs, or herbaceous vegetation.
- Shrub Communities—Identified on aerial photos by reflectance values (determined visually) of trees (dark) and rock (light), vegetation height ranging from 0 to 10 m, and round crown shape.
- Grass/Forb Communities—Communities characterized by dominance by grass or forb species.

Following delineation of basic structural classes, we identified areas with habitat features important to wildlife. Important habitat features included:

- riparian and wetland areas,
- stands with a deciduous or veteran component,
- selectively harvested areas,
- avalanche paths,
- stands with multiple canopy layers, and
- stands with sparse overstorey canopy cover (<25%).

Minimum polygon size was set at 2 ha to ensure that mapping did not become too detailed to be useful operationally.

Field Sampling

We selected five structural attributes to measure: vertical structure (canopy cover), density of coarse woody debris, horizontal structure (forest patchiness), depth of litter and duff layer, and tree size, each of which has been noted as an important component of wildlife habitat and could be easily measured in the field (Thomas 1979; Bartels *et al.* 1985; Thomas and Verner 1986; Hodorff *et al.* 1988; Maser *et al.* 1988; Hunter 1990; Graham *et al.* 1994).

In each study area, we measured these attributes in nested circular plots that were 10 m in radius (314 m^2) and 25 m in radius (1962 m^2) and randomly distributed within structural classes. The number of classes we sampled varied by study area (Table 1). We tried to sample class combinations that were either biologically significant (e.g., riparian areas) or operationally important (e.g., Early Seral Forest, Immature Forest, Mature Forest, and Old Forest classes). The number of plots measured in each structural class depended on the size of the structural class; we attempted to measure at least seven plots in each structural class per study area, based on variability of measured parameters from a pilot study (Hurlburt *et al.* 1997).

In the 10-m plots, we measured:

- Coarse woody debris—Counted in the plot in three diameter classes: small (7.5–20 cm), medium (20–40 cm), and large (>40 cm).
- Percent canopy closure—Estimated by sight for three height classes (listed below).
- Tree height of three canopy layers—Canopy layer definitions followed those described in Luttmerding *et al.* (1990): A Layer included mature trees >10 m in height; B1 Layer included regenerating trees, mature deciduous trees, tall shrubs, or woody plants 2–10 m in height; B2 Layer included shrubs or regenerating trees <2 m in height. The average height of each layer was also measured.
- Species composition—The two most abundant species present in each canopy layer were recorded.
- Depth of litter and duff layer—Measured at five systematically placed locations around the plot.

In the 25-m plots, we collected information about standing live and dead trees. For each tree, we recorded tree species, diameter at breast height (dbh) for all live trees >30 cm dbh, and dbh for all dead trees of any size. We used the wildlife tree classification of Thomas *et al.* (1979) to describe the decay stage of all trees.

Statistical Analysis

Structural Differences Between Structural Classes, by Study Area

We used one-way ANOVA (analysis of variance) (SAS 1987) to test for differences in abundance of structural features between structural classes in each study area. Data was analyzed separately for each study area in case there were differences in structural features between study areas that were not readily apparent. Homoscedasticity was determined using the Levene's test (SAS 1987). Log, square root, or arcsine transformations were used to transform variables that did not meet the assumption of equal variance required by ANOVA. If variables did not meet the assumption of equal variance despite transformation, the more robust Welch's ANOVA was used in the analysis (Day and Quinn 1989). The GT2 unplanned multiple comparison test was used to determine which group means differed from each other for variables that met the homogeneity of variance assumption (SAS 1987). The Sidak unplanned multiple comparison test was used to

TABLE 1. Sample sizes by structural class for the Grohman Creek, Sheppard Creek, and Perry Ridge study areas.

	Structural class									
Study area	Early Seral Forest, *n*	Immature Forest, *n*	Immature Forest/ deciduous leading, *n*	Immature Forest/ riparian, *n*	Mature Forest, *n*	Mature Forest/ deciduous leading, *n*	Mature Forest/ riparian, *n*	Old Forest, *n*	Old Forest/ riparian, *n*	Shrub Communities, *n*
Sheppard Creek	11	30	20	18	62	0	10	24	5	5
Grohman Creek	19	26	16	14	39	8	17	71	8	0
Perry Ridge	10	27	22	8	24	17	7	23	6	6

determine which group means differed from each other for variables that did not meet the homogeneity of variance assumption (SAS 1987). Some structural classes and subclasses had small sample sizes and were grouped for analytic purposes. We often grouped the Shrub Communities and Early Seral Forest classes when analyzing tree size and density, and Mature Forest and Old Forest/riparian classes when analyzing canopy closure. We considered test results significant at the level of $p = 0.05$ (Table 2).

Structural Diversity Index

For the Perry Ridge study area, we developed a structural diversity index to identify sample sites and polygons with high structural diversity. Each sample plot was ranked in relation to all other plots sampled in the study area. To determine which habitat features should be used in the index, we reviewed the literature to determine which were important to wildlife. As the basis of our index we chose nine variables, all of which have been noted as important components of wildlife habitat (MacArthur and MacArthur 1961; Thomas 1979; Marzluff and Lyon 1983; Bartels *et al.* 1985; Thomas and Verner 1986; Hodorff *et al.* 1988; Maser et al. 1988; Hunter 1990; Graham *et al.* 1994; Ruggiero *et al.* 1994; Carey and Johnson 1995; Marcot 1997); these were measured in the field or mapped during habitat mapping, and included:

1. number of large live trees (>50 cm dbh)

TABLE 2. Statistical test used and *p* value for tests of differences in structural features

	Grohman Creek		Sheppard Creek		Perry Ridge	
Structural feature	Test used	*p* value	Test used	*p* value	Test used	*p* value
Live tree density (>30 cm, no. trees/ha)	Welch's ANOVA	0.0001	ANOVA	0.0001	Welch's ANOVA	0.0001
Dead tree density (>10 cm, no. trees/ha)	Welch's ANOVA	0.0001	Welch's ANOVA	0.0001	ANOVA	0.0001
Live tree density (trees >50 cm, no. trees/ha)	Welch's ANOVA	0.0001	ANOVA	0.0001	Welch's ANOVA	0.0001
Dead tree density (trees >50 cm, no. trees/ha)	Welch's ANOVA	0.0001	ANOVA	0.0001	ANOVA	0.0001
Live tree diameter (cm)	ANOVA	0.0001	ANOVA	0.0001	ANOVA	0.0001
Dead tree diameter (cm)	ANOVA	0.0001	ANOVA	0.0001	ANOVA	0.0001
Small woody debris density (no. pieces/ha)	Welch's ANOVA	0.0001	ANOVA	0.0001	ANOVA	0.0968
Medium woody debris density (no. pieces/ha)	Welch's ANOVA	0.1717	ANOVA	0.0446	ANOVA	0.0001
Large woody debris density (no. pieces/ha)	Welch's ANOVA	0.0266	Welch's ANOVA	0.0141	Welch's ANOVA	0.0001
A Layer closure (%)	Welch's ANOVA	0.0001	Welch's ANOVA	0.0001	Welch's ANOVA	0.0001
B2 Layer closure (%)	Welch's ANOVA	0.0001	Welch's ANOVA	0.0001	ANOVA	0.0002
B1 Layer closure (%)	Welch's ANOVA	0.4281	Welch's ANOVA	0.0001	Welch's ANOVA	0.0001
Litter and duff layer depth	ANOVA	0.0001	ANOVA	0.0001	ANOVA	0.0001

2. number of large dead trees (>50 cm dbh)
3. number of pieces of large coarse woody debris (>40 cm)
4. foliage height diversity
5. distance to riparian or wetland habitats
6. number of pieces of small coarse woody debris (7.5–20 cm)
7. depth of litter and duff layer
8. presence of a deciduous component
9. number of dead trees >10 cm dbh

Foliage height diversity was derived from canopy closure estimates using the equation

$$(-\sum_{1} p_i \log_e p_i)$$

where

p = total percent canopy cover of foliage in a canopy layer (MacArthur and MacArthur 1961).

We designed an additive index where sites with more structure were assigned higher values. If the site had values for an individual variable that were higher than the mean values for the structural class, the site was given a rating of +1 or +2. Sites with values below the mean for individual variables were given a rating of 0. We completed a literature review to determine the relative importance of each variable to forest-dwelling wildlife species.

Variables 1 to 4 in the list above were determined to be more important habitat variables than were the remaining attributes (Thomas 1979; Maser *et al.* 1979; Thomas *et al.* 1988). If the site had values for these variables that were higher than the mean values for the structural class, the site was given +2 for each variable with an observation greater than the mean. If the site had values above the mean for variables 6, 7, and 9 in the list above, a deciduous component was present, or if the site was within 1 km of a riparian or wetland area, the site was given +1 for each variable. We added the total number of points attributed to each site and compared totals within structural classes. Plots with total scores in the lower 25th percentile were classified as Low structural diversity sites; plots with total scores between the 26th and 75th percentiles were classified as Moderate structural diversity sites, and sites with total scores above the 75th percentile were classified as High structural diversity sites.

Results

Structural Classes

All three study areas were largely forested and dominated by mid-seral structural classes, with the Old Forest structural class occupying <20% of the landscape in all cases. Non-forested areas—such as rock, grass/forb, shrub, and alpine communities—made up <16% of each study area.

Both the Grohman and Perry Ridge areas were largely made up of Immature Forest, Mature Forest, and Old Forest, while the Sheppard Creek area was dominated by Immature Forest and Mature Forest with little Old Forest found there. The Early Seral Forest structural class was uncommon in all three areas.

Structural Feature Inventory

Structural values were different between structural classes in all study areas, except in the closure of the B1 Layer and density of medium coarse woody debris in the Grohman study area, and density of small woody debris in the Perry Ridge study area (Tables 3, 4, and 5).

Forested areas and riparian sites were more structurally complex than non-forested and upland sites. As expected, areas classed as Shrub Communities and Early Seral Forest had lower live and dead tree densities ($p < 0.001$), lower A Layer canopy closure ($p < 0.001$), and higher B1 Layer canopy closure ($p < 0.001$ for Sheppard Creek and Perry Ridge) (Tables 3, 4, and 5). Early Seral Forest generally had more small coarse woody debris (818 ±562 in Grohman Creek, 590±265 in Sheppard Creek) than other structural classes ($p < 0.001$). Riparian areas in Old Forest sites generally had larger live trees (e.g., 53 cm dbh ±26 for Old Forest/riparian areas in Sheppard Creek) and dead trees (e.g., 39 cm dbh ±16 for Old Forest/riparian areas in Perry Ridge), more large woody debris (e.g., 134 ±73 pieces/ha for Old Forest/riparian areas in Perry Ridge), and a deeper litter and duff layer than upland sites (Tables 3, 4, and 5).

Old Forests were more structurally complex in the tree layer than were Immature Forests. Generally, Old Forests had greater densities of large live trees (over 50 cm dbh) (e.g., 50 ±37 trees per ha for Old Forests in Perry Ridge; $p < 0.001$), and larger dead trees (e.g., 27 ±14 cm dbh for Old Forests in Grohman Creek; $p < 0.001$). Forests with a deciduous component were structurally similar to coniferous forests.

Structural Diversity Index

Structural diversity values ranged from 10 to 30, with stands in the Immature Forest, Shrub Communities, and Early Seral Forest classes dominating the Low category and stands in the Old Forest and Mature Forest classes dominating the High category (Table 6).

TABLE 3. Comparison of mean and standard deviation for 11 forest structural variables and 9 structural classes, Grohman Creek Wildlife Habitat Inventory, 1997.

	Structural class								
Structural feature	Early Seral Forest	Immature Forest	Immature Forest/ deciduous leading	Immature Forest/ riparian	Mature Forest	Mature Forest/ deciduous leading	Mature Forest/ riparian	Old Forest	Old Forest/ riparian
Live tree density (>30 cm, no. trees/ha)	2 (4)^{a**}	35 (39)^{b}	45 (28)^{bd}	79 (43)^{cd}	104 (58)^{c}	85 (43)^{cd}	148 (97)^{cd}	142 (71)^{c}	153 (73)^{c}
Dead tree density (>10 cm, no. trees/ha)	3 (6)^{a}	55 (46)^{bdef}	42 (29)^{bchij}	30 (14)^{ackl}	122 (140)^{gmn}	19 (24)^{adho}	37 (26)^{aeimp}	65 (65)^{bknop}	62 (77)^{afjln}
Live tree density (trees >50 cm, no. trees/ha)	0.6 (2)^{ai}	6 (18)^{acd}	2 (5)^{a}	4 (7)^{af}	13 (16)^{bcf}	16 (11)^{bdfh}	See Old Forest/ riparian	50 (45)^{ehi}	48 (30)^{gh}
Dead tree density (trees >50 cm, no. trees/ha)	3 (6)^{a}	19 (30)^{acde}	12 (27)^{a}	20 (15)^{afgh}	106 (148)^{bcfi}	16 (25)^{aij}	See Old Forest/ riparian	60 (67)^{bdgj}	49 (57)^{behj}
Live tree diameter (cm)	52 (36)*	39 (11)^{a}	34 (6)^{b}	138 (9)^{a}	39 (9)^{ad}	41 (11)^{a}	47 (16)^{c}	49 (20)^{de}	47 (18)^{ce}
Dead tree diameter (cm)	17 (7)*	18 (10)^{a}	25 (13)^{bce}	24 (17)^{acf}	21 (9)^{dg}	26 (15)^{aegi}	36 (17)^{h}	27 (14)^{bfi}	25 (15)^{bfi}
Small woody debris density (no. pieces/ha)	818 (523)^{a}	197 (1)^{bcd}	143 (80)^{bef}	160 (70)^{acegh}	221 (232)^{bgi}	See Mature Forest	See Old Forest/ riparian	256 (218)^{dfij}	145 (106)^{bhj}
Medium woody debris density (no. pieces/ha)	75 (86)^{a}	70 (86)^{a}	92 (149)^{a}	73 (54)^{a}	82 (73)^{a}	88 (94)^{a}	68 (60)^{a}	115 (97)^{a}	108 (45)^{a}
Large woody debris density (no. pieces/ha)	10 (19)^{a}	8 (33)^{a}	46 (86)^{a}	46 (61)^{a}	19 (28)^{a}	32 (38)^{a}	44 (54)^{a}	39 (46)^{a}	64 (85)^{a}
A Layer closure (%)	9 (19)^{a}	31 (22)^{b}	40 (16)^{b}	51 (14)^{b}	43 (18)^{b}	37 (20)^{b}	49 (19)^{b}	42 (16)^{b}	39 (9)^{b}
B2 Layer closure (%)	9 (11)^{a}	37 (20)^{ac}	49 (23)^{ae}	30 (19)^{bcf}	24 (21)^{bceg}	35 (16)^{aefh}	34 (23)^{aefi}	22 (18)^{dghi}	27 (22)^{bhi}
B1 Layer closure (%)	58 (20)^{a}	47 (26)^{a}	55 (30)^{a}	45 (31)^{a}	52 (26)^{a}	59 (31)^{a}	34 (23)^{a}	45 (22)a	51 (37)^{a}
Litter and duff layer depth	4 (2)^{af}	5 (4)^{bcg}	6 (3)^{bdei}	4 (2)^{acdg}	4 (3)^{gi}	6 (2)^{bchi}	7 (4)^{efgh}	4 (3)^{aci}	4 (3)

* Structural class not included in analysis.

** Values with the same letters are not significantly different from each other at $p < 0.05$.

Based on the structural index, we rated 13 stands as High diversity sites—these included two stands in the Immature Forest class, five in the Mature Forest class, and six in the Old Forest class. The two Immature Forest sites rated as High diversity were both upland sites. All five High diversity/Mature Forest sites were upland sites; High diversity/Old Forest stands varied greatly in size and were located in upland areas throughout the study area.

Discussion

Structural Inventory

Across the forest structural classes defined in this study, the differences we found in structural complexity of forests in southeastern British Columbia were similar to those previously reported for the Pacific Northwest (Franklin and Spies 1991; Hansen *et al.* 1991; Carey and Johnson 1995; Hansen *et al.* 1995). The exception was,

TABLE 4. Comparison of mean and standard deviation for 11 structural variables compared in 9 structural classes, Sheppard Creek Wildlife Habitat Inventory, 1997.

	Structural class								
Structural feature	Early Seral Forest	Immature Forest	Immature Forest/ deciduous leading	Immature Forest/ riparian	Mature Forest	Mature Forest/ riparian	Old Forest	Old Forest/ riparian	Shrub Communities
Live tree density (>30 cm, no. trees/ha)	0 (0)^{a***}	96 (61)^{bd}	60 (55)^{b}	110 (56)^{bd}	122 (59)^{cd}	202 (38)^{cd}	144 (69)^{cd}	181 (29)^{cd}	0 (0)*
Dead tree density (>10 cm, no. trees/ha)	0 (0)^{a}	11 (13)^{ac}	5 (7)^{a}	11 (16)^{ad}	25 (29)^{bdc}	46 (28)^{e}	27 (25)^{bc}	72 (18)^{e}	0 (0)*
Live tree density (trees >50 cm, no. trees/ha)	2 (8)^{a}	58 (55)^{bc}	57 (61)^{ab}	54 (35)^{bc}	63 (68)^{bd}	61 (39)^{b}	79 (80)^{d}	68 (31)^{bc}	89 (19)*
Dead tree density (trees >50 cm, no. trees/ha)	0 (0)^{ac}	1 (1)^{bd}	1 (1)^{bc}	1 (1)^{bd}	5 (2)^{bd}	4 (1)^{b}	4 (1)^{d}	15 (8)^{bd}	0 (0)*
Live tree diameter (cm)	**	39 (9)^{a}	37 (8)^{a}	38 (8)^{a}	42 (11)^{b}	43 (13)^{b}	42 (12)^{b}	53 (26)^{c}	**
Dead tree diameter (cm)	19 (7)^{af}	20 (9)^{b}	17 (11)^{a}	25 (11)^{c}	25 (16)^{de}	28 (18)^{dg}	26 (14)^{ceg}	42 (37)^{f}	**
Small woody debris density (no. pieces/ha)	590 (265)^{a}	271 (166)^{b}	207 (182)^{b}	207 (98)^{ab}	344 (279)^{ab}	290 (156)^{ab}	325 (269)^{ab}	465 (278)^{ab}	210 (107)^{ab}
Medium woody debris density (no. pieces/ha)	101 (51)^{a}	72 (64)^{a}	56 (94)^{a}	96 (59)^{a}	117 (95)^{a}	159 (121)^{a}	121 (75)^{a}	83 (62)^{a}	0 (0)^{a}
Large woody debris density (no. pieces/ha)	9 (15)^{a}	16 (27)^{a}	13 (22)^{a}	20 (45)^{a}	44 (51)^{a}	51 (55)^{a}	35 (39)^{a}	38 (52)^{a}	0 (0)^{a}
A Layer closure (%)	73 (1)^{a}	52 (23)^{bd}	40 (26)^{b}	45 (9)^{be}	55 (18)^{cde}	68 (14)^{cef}	53 (23)^{bf}	83 (9)^{ce}	0 (0)*
B2 Layer closure (%)	7 (10)^{abd}	38 (24)^{abd}	34 (19)^{b}	55 (14)^{b}	28 (20)^{de}	26 (12)^{abdf}	30 (21)^{de}	23 (27)^{cef}	0 (0)*
B1 Layer closure (%)	40 (28)^{b}	46 (29)^{c}	68 (21)^{a}	73 (20)^{c}	32 (32)^{d}	8 (6)^{d}	33 (28)^{cd}	9 (8)^{d}	77 (16)^{bcd}
Litter and duff layer depth	3 (3)^{a}	5 (4)^{abcd}	4 (3)^{a}	5 (3)^{bef}	5 (3)^{ceg}	7 (3)^{h}	5 (3)^{dfg}	10 (6)^{i}	1 (1)^{a}

* Structural class not included in analysis.
** Values not included due to small sample size.
*** Values with the same letters are not significantly different from each other at $p < 0.05$.

other than differences in tree structure, we found relatively few structural differences between the Old Forest class and other forested structural classes. In our study, density of large live trees, and sizes of both live and dead trees, were generally higher in areas classed as Old Forest than in areas classed as Mature Forest. We suspect that many Old Forest stands in the southwestern part of the West Kootenay region are not old enough to have developed classic old-growth characteristics such as canopy gaps, high abundance of large coarse woody debris, and deep litter and duff layers.

As expected, stands classified as forested (Old Forest, Mature Forest, and Immature Forest) were more structurally complex than those classified as Shrub Communities and Early Seral Forest. Harvested areas contained more small coarse woody debris than stands in older classes. Cable yarders are the most common timber yarding system in mountainous areas of British Columbia. It is difficult to leave standing trees using this system and the small number of large live trees and dead trees of all sizes in all harvested stands reflected this limitation. Cable-harvested stands have considerable structure on the ground early in the rotation (Mowat *et al.* 2000), but we expect they will be structurally poor later in the rotation because there are few large live and dead trees left for recruitment of coarse woody debris.

Riparian areas were more structurally complex than upland sites, likely due to the high biomass production that results from the abundance of water in riparian areas. Due to the steep slopes found in this region, riparian areas were generally small linear communities, rarely more than 15 m wide.

TABLE 5. Comparison of mean and standard deviation for 11 structural variables compared in 8 structural classes, Perry Ridge Wildlife Habitat Inventory, 1997–1998.

	Structural class							
Structural feature	Early Seral Forest	Immature Forest	Immature Forest/ riparian	Mature Forest	Mature Forest/ riparian	Old Forest	Old Forest/ riparian	Shrub Communities
Live tree density (>30 cm, no. trees/ha)	21 (26)^{a**}	97 (62)^{ac}	178 (69)^{bcd}	106 (73)^{bc}	186 (75)^{bce}	197 (56)^{de}	234 (147)^{bce}	0 (0)^{a}
Dead tree density (>10 cm, no. trees/ha)	1 (2)^{a}	15 (21)^{ad}	43 (22)^{b}	15 (19)^{ce}	41 (36)^{bde}	50 (37)^{b}	86 (23)^{b}	0 (0)^{a}
Live tree density (trees >50 cm, no. trees/ha)	17 (21)^{ad}	85 (95)^{ac}	48 (53)^{adef}	147 (150)^{bce}	55 (31)^{acg}	115 (88)^{bcf}	43 (49)^{ac}	0 (0)^{dg}
Dead tree density (trees >50 cm, no. trees/ha)	2 (3)^{a}	3 (5)^{a}	13 (16)^{a}	4 (6)^{a}	4 (8)^{a}	9 (11)^{a}	15 (26)^{a}	0 (0)*
Live tree diameter (cm)	36 (5)^{a}	40 (10)^{a}	43 (14)^{bc}	39 (11)^{a}	38 (8)^{ace}	42 (13)^{be}	46 (12)^{d}	0 (0)*
Dead tree diameter (cm)	27 (16)^{a}	20 (12)^{b}	34 (29)^{cde}	19 (10)^{b}	22 (10)^{ade}	26 (15)^{ae}	39 (16)^{c}	0 (0)*
Small woody debris density (no. pieces/ha)	398 (239)^{a}	365 (431)^{a}	800 (810)^{a}	463 (348)^{a}	1007 (585)^{a}	382 (332)^{a}	548 (569)^{a}	361 (360)^{a}
Medium woody debris density (no. pieces/ha)	150 (111)^{abc}	97 (104)^{a}	378 (108)^{bde}	120 (106)^{a}	466 (239)^{cdf}	191 (128)^{aef}	299 (409)^{cdf}	53 (48)^{a}
Large woody debris density (no. pieces/ha)	73 (67)^{ae}	36 (40)^{ae}	235 (168)^{bc}	45 (54)^{a}	235 (186)^{b}	69 (54)^{dfe}	134 (73)^{acf}	42 (52)^{ae}
A Layer closure (%)	8 (13)^{af}	39 (19)^{bc}	49 (25)^{bd}	33 (14)^{be}	48 (18)^{bg}	44 (16)^{cdefg}	53 (10)^{bg}	1 (1)a
B2 Layer closure (%)	49 (19)^{a}	27 (16)^{acd}	21 (19)^{aefg}	19 (14)^{bcehi}	20 (10)^{ahj}	13 (12)^{bfj}	26 (20)^{aij}	22 (29)^{bdgj}
B1 Layer closure (%)	60 (22)^{a}	41 (27)^{ac}	16 (23)^{bcd}	42 (25)^{a}	41 (22)^{ad}	41 (28)^{ad}	21 (10)^{ad}	68 (33)$_{a}$
Litter and duff layer depth	3 (3)^{a}	4 (3)^{ad}	7 (4)^{bei}	4 (3)^{df}	5 (4)^{aefg}	5 (4)^{bdg}	10 (4)^{i}	9 (7)^{bgi}

* Structural class not included in analysis.

** Values with the same letters are not significantly different from each other at $p < 0.05$.

There were few structural differences between stands with a deciduous component and pure coniferous stands. Nevertheless, deciduous stands may deserve greater consideration in biodiversity planning than pure conifer stands because they generally have greater wildlife species diversity than pure conifer forests (Hunter 1990; Bunnell *et al.* 1999). For this reason, the number of deciduous trees became an important variable in our structural index.

Structural Diversity Index

The considerable variation in our structural diversity index between sites suggests this is an effective method to rank structural diversity of stands. We suggest that careful consideration be given to all structurally diverse forest stands in this region and that as many stands as possible be given special management consideration. Old Forest stands have been identified as an important component of wildlife habitat in forests in British Columbia (BC Ministry of Forests and BC Ministry of Environment 1995), but land managers should also focus on High diversity sites in the Immature Forest and Mature Forest classes as well. In fact, over half of the High diversity sites identified in the Perry Ridge study area were in areas classified as Immature Forest and Mature Forest. In the southwest of the Kootenay region, it is often necessary to select young stands to be recruited into the old-growth seral stage within landscape units to meet the seral stage requirements of the Forest Practices Code of British Columbia. We suggest the most structurally diverse younger stands are the best candidates for recruitment.

Limitations of the Study

Some variables turned out to be poor measures of structure between classes. Raw measurements of forest

TABLE 6. Examples of structural diversity index values for sampled plots, Perry Ridge Wildlife Habitat Inventory, 1997–1998.

Plot	Structural Class	Diversity Index Value	Structural Diversity Rating
90	Mature Forest	10.00	Low
1003	Early Seral Forest	11.00	Low
229	Early Seral Forest	12.00	Low
289	Shrub Communities	12.00	Low
93	Immature Forest	13.00	Low
147	Shrub Communities	15.33	Moderate
52	Immature Forest/deciduous leading	15.50	Moderate
201	Immature Forest/deciduous leading	16.00	Moderate
32	Immature Forest/deciduous leading	16.50	Moderate
216	Early Seral Forest	16.50	Moderate
8	Mature Forest	17.00	Moderate
23	Mature Forest	17.00	Moderate
101	Immature Forest	17.00	Moderate
49	Immature Forest/deciduous leading	17.43	Moderate
350	Immature Forest	18.00	Moderate
5	Early Seral Forest	18.50	Moderate
39	Immature Forest/deciduous leading	19.00	Moderate
36	Mature Forest/deciduous leading	19.50	Moderate
198	Mature Forest	19.75	Moderate
22	Old Forest	20.00	Moderate
45	Mature Forest/deciduous leading	20.00	Moderate
124	Immature Forest	20.00	Moderate
203	Immature Forest	20.00	Moderate
260	Immature Forest/deciduous leading	20.00	Moderate
202	Immature Forest/deciduous leading	20.33	Moderate
20	Immature Forest	20.40	Moderate
112	Mature Forest	20.71	Moderate
161	Immature Forest	22.67	High
4	Old Forest	23.00	High
56	Old Forest	23.67	High
109	Old Forest	24.00	High
123	Immature Forest	24.00	High
130	Old Forest	24.00	High
174	Mature Forest/deciduous leading	24.00	High
95	Mature Forest	24.50	High
43	Old Forest	27.00	High
99	Old Forest	27.00	High
245	Mature Forest	27.00	High
222	Mature Forest	28.00	High
181	Mature Forest	30.00	High

patchiness and A Layer closure only confirmed the obvious: structural complexity in the tree layer is lower in clearcuts than in forested stands. Forest patchiness was not significantly different between any other classes. Similarly, closure of A Layer was not significantly different for the Sheppard Creek and Grohman Creek study areas, but in the Perry Ridge study area we found that closure of A Layer was higher in stands classified as Immature Forest than in stands classified as Old Forest. Sizes of live trees and dead trees are closely tied to densities of large live trees and large dead trees respectively, thus analysis of tree size is largely repetitive. The value of measuring tree size was to derive size categories to analyze tree density, particularly the large live and dead tree groups. Several other variables, such as the number of deciduous trees, the number of small live trees, tree height, and numbers of pieces of both small and medium coarse woody debris, did not consistently show differences among structural classes.

The delineation of different structural classes through aerial photo interpretation worked better in larger study areas because structural class diversity tends to increase with increasing study area size. A very similar inventory on a 600-ha area near Nelson (Hurlburt *et al.* 1997) revealed fewer differences between structural classes than were found in the larger study areas reported here. The methods presented here may be more revealing for larger study areas.

As the study progressed, we were able to reduce data-collection costs per plot through improved planning and more efficient fieldwork. Field sampling costs varied by study area—generally, larger or more heterogeneous study areas required more sampling than did small or homogeneous study areas. The number of plots sampled per study area ranged from 150 to 218. We estimate that a two-person crew could sample four to ten plots per day. The main factors affecting productivity in the field were travel time between plots and the number of trees in each plot. Careful planning of access and routes can save time. We had to use helicopters to access sites in several study areas, which greatly increased costs. Generally, larger study areas will cost less per hectare, but there will be less stand-level information to aid in forest management prescriptions. A sensible way to increase cost effectiveness would be to collect structural data during pre-harvest stand prescriptions and forest inventories. Another alternative would be to use a less expensive method to stratify habitats, such as remote sensing data or use of forest cover polygons. Aerial photo interpretation could be reserved for specific needs such as mapping of avalanche chutes for grizzly bear habitat assessment.

Conclusions

We present a method to delineate forest structural classes and inventory structural features important to forest-dwelling wildlife species. This method is based on the differences we found in abundance of structural features between structural classes on three study areas in the West Kootenay region of southeastern British Columbia in 1997–98. Additionally, we show how we ranked individual stands based on the abundance of these structural features. This information can be used by land managers to help identify sites with high structural diversity, or as baseline values to guide structural retention during harvesting.

Acknowledgements

This project was funded by Forest Renewal BC through Kalesnikoff Lumber Company and Atco Lumber, and by the British Columbia Ministry of Sustainable Resource Management. Impetus for this project came from Dr. Mike Panian, Regional Inventory Biologist, Kootenay Region, British Columbia Ministry of Sustainable Resource Management. We thank C. Shurgot, A. Walker, M. Marrello, and D. Stanley for their assistance with the field work; J. Boulanger for assistance with data analysis; and three anonymous reviewers for their comments on this paper.

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