Stand Structure Classification: 
A Quantitative Approach

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Abstract

There is need for a precise, consistent and verifiable means of communicating differences and similarities in stand structures to improve the design and implementation of forest management practices.

Stand structures are defined based on differences in the total numbers of trees per hectare with respect to decreasing diameter, starting with the largest tree in each plot or stand. This is referred to as the “Cumulative Distributions Approach” to classification. Seventeen distinct classes are defined based on 422 plots established throughout the Cariboo region of British Columbia (centred in Williams Lake). The 17 classes represent conditions ranging from those described as “Even-aged” with a narrow range of tree diameters, to “Uneven-aged” with a wide range of tree diameters.

A graphical and pictorial description is presented for each stand structure class.
INTRODUCTION

The Importance of Stand Structure Classification

Why classify stand structures? The purpose is to enable consistent, precise and verifiable communication about the expected diameter distribution of trees within a stand. This purpose might be extended to include the distribution of trees with respect to both species and diameter. Stand structure classification enables people to discuss certain kinds of stand types, for example A versus B, in a way that ensures they have the same interpretation of what the differences in fact are. To the extent that the differences between stand structures can be clearly and consistently defined in simple terms by many different observers, forest management practices can be more consistently applied to produce desired outcomes.

Why are differences in stand structure important? They are important to all aspects of forest management. Wildlife species habitats are typically described at various scales in terms of number of trees or basal area per hectare or percent cover of a given species composition within certain size classes. Sometimes these descriptions are reduced to average stand statistics, such as quadratic mean diameter. The problem with this kind of statistic is that the same average can be produced from significantly different distributions of tree diameters. If a more detailed description of the expected diameter distributions were available, then perhaps more reliable estimates could be made with respect to species habitat uses and requirements.

Differences in stand structure, insofar as these reliably infer differences in diameter distributions, are important for developing silviculture and harvesting regimen and so too, forecasting log supplies relative to differences in quality (e.g. Sawlog, Gang, Pulp); this is particularly so where every stand has not been ground sampled. Stand structure classification can be used to pre-stratify forested areas to reduce the costs of sampling and increase levels of precision with which stands are characterized (based on a consistent definition being applied by different interpreters). Stand structure classification can be used to reliably generate stand and stock tables for each inventory polygon, even if those polygons have not been ground sampled. It can be used for generating inventory polygon tree lists needed for forecasting future forest conditions using an individual tree growth model; this allows for the rapid development of localized growth and mortality curves. The distributions of stand structures within a landscape can be used to better describe natural disturbance patterns and in so doing improve the chances of successfully maintaining biodiversity.

Traditional Approaches To Stand Structure Classification

O’Hara et al (1996) provided an overview of recent efforts in the Pacific northwest to classify stands based on structural or physiognomic characteristics. To set the stage for their work they refer to three major components of structure as follows (Kershaw 1964): a) vertical, b) horizontal, and c) quantitative. Quantitative structure can be further specified according to life
forms, floristics, or size class distributions (Mueller-Dombois and Ellenberg, 1974). The system of classification described in this paper falls within the latter category. In my opinion, it seems easier to build and apply a system of classification based on differentiation of size class distributions that in turn have characteristic vertical and horizontal distributions. This is instead of starting with vertical or horizontal characteristics, that are sometimes difficult to describe, and then trying to integrate size class differences lower in the classification hierarchy.

O’Hara et al. (1996) go on to discuss some of the structural systems of classifications, such as that of Thomas (1979) for stands in the Blue Mountains of Oregon and Washington. Thomas described stands in a progression, barring any disturbance, starting with clearcutting, through dense seedlings and saplings, saplings and poles, poles, small sawtimber and large sawtimber, and old growth. According to O’Hara these stand conditions primarily represent vertical structure but their quantification is usually based on average diameter at breast height. The issue raised by this comment is that there may be significantly different diameter distributions associated with the same average stand diameter. The result is that this kind of a classification is really lacking in the precision with which stand structures can be defined, making it less reliable to apply to anything other than strictly even-aged management.

The position taken by O’Hara et al (1996) was that, “… a structural vegetation classification based on stand-development processes reflects fine- and coarse-grained processes which operate across stands and landscapes.” This led them to the development of the following classification:

A. Stand initiation
B. Open stem exclusion
C. Closed stem exclusion
D. Understory reinitiation
E. Young multi-strata
F. Old forest multi-strata
G. Old forest single-stratum

For each of these categories there is both a definition and a description that forms the basis for its application. For example, the Young multi-strata type (E) is described as follows:

Definition: Two or more cohorts present through establishment after periodic disturbances including harvest events.

Description: Multi-aged (multi-cohort) stand with an assortment of tree sizes and canopy strata present but very large trees absent. Grasses, forbs, and shrubs may be present.

These definitions and descriptions do indeed represent an improvement over the Thomas (1979) system of classification. The issue that remains is how do two or more independent observers consistently distinguish one group from another? It would be preferable if these labels were underwritten by a more quantitative approach to distinguishing one group from another.

To begin with then, it is desirable to produce a quantitative basis for stand structure classification, but it is by no means obvious how this could be achieved. How do we deal with
the fact that the answer will change depending on the scale of observations (plot, stand, landscape)? How do we deal with the fact that there is a continuum of stand structures so that there is seemingly no optimal way to decide where one class ends and another begins? If the classification were to be quantitative then we need to begin with some actual plot data, or at minimum find a way to consistently apply the classification to that kind of information. How should we compare two sets of plots, one fixed radius and the other variable? What happens when trees are recorded as being in different sets of plots based on differences in the minimum diameters? It is be best to avoid using diameter classes as the basis for differentiating stand types because any such definition would introduce a degree of arbitrariness into the system of classification. What is needed is a system that works regardless of where the diameter class boundaries might be located. It is this last consideration that leads to the Cumulative Distribution Approach.

Other Alternatives to Characterizing Diameter Distributions – The Weibull Distribution

What about other methods of estimating diameter distributions such as the use of Weibull probability distributions (for example see Bailey and Dell, 1973)? Firstly stand structure classification might be used to describe in more simple terms different classes by subdividing the Weibull distribution parameter-space into classes such that the within class variation in (normalized) parameters is minimized. On this basis, communications to general audiences could be simplified. At a deeper level it may be preferred to use the actual distributions of trees without regard to any of the known distributions. For example, where there is a stand consisting of two layers, more than one Weibull distribution would be needed to adequately describe it. This point can be extended to 3,4,5… n different layers. Stand structure classification based on actual distributions tend to represent more realistic tree diameter distributions.

What follows is a more complete description of the Cumulative Distribution Approach to classification. It is heavily weighted toward pictures and graphs so as to demonstrate the ease with which it can be used by a wide variety of Professionals in the field (also see Farnden at al. 2003).

METHODS

The Dataset

The stand structure classification was originally developed for Lignum Ltd (now owned by Riverside Forest Products Ltd) in the south central interior region (Cariboo) of British Columbia (Figure 1). Four hundred and twenty two plots were established in a wide variety of stands, mostly dominated by lodgepole pine (Pinus contorta var. latifolia Dougl.) and Douglas-fir (Pseudotsuga menziesii var. glauca (Beissn.) Franco). Stand structures vary from ones having a narrow to wide range of diameters, these being due to historical fire regimes ranging from frequent, low intensity regimes (stand initiating, particularly in stands of Douglas-fir) to less frequent high intensity regimes (stand replacing, particularly in stands dominated by lodgepole pine). At low elevations (700 metres) selection cutting has been practiced for a long period of time, latterly to promote successful Douglas-fir regeneration. Site indices range from 8 metres at 50 years (breast height age), predominantly to the west of Williams Lake (dominated by cold,
dry conditions) to 24 metres to the east (dominated by warmer, moister conditions). The end result of both natural and man-made disturbances is that there are a wide variety of stand structures in the landscape. Of the 422 plots, approximately 60% of them were subjectively located as 1/10th hectare permanent sample plots to represent a wide variety of stand conditions, while the remainder (combined prism and fixed area plots) were established at random (using a sorted list and systematic sampling) to represent a wide variety of stands within a 600,000 hectare inventory.

![Figure 1. The stand structure classification was developed using 422 plots representing a variety of stand types in the Riverside Forest Products’ operating areas (shown in orange in the main map) and more specifically in the Lignum operating area shown in light green in the inset (approximately 600,000 hectares of which is forested).](image)

**Analysis**

To develop the classification two cumulative distributions were produced to represent each plot (Moss, 2003), one representing basal area per hectare (BAPH; see Figure 2) and the other trees per hectare (TPH). To build a cumulative distribution, start with the diameter of the largest tree rounded up to the nearest centimetre. Subtract 1 cm from the maximum and sum the trees per hectare and basal areas per hectare greater than or equal to that figure. Repeat this process until dbh is equal to 0. These cumulative distributions are then each converted to scale between 0 and 1 (normalization). Compare the pair of normalized distributions for each plot with every other plot by subtracting the differences for BAPH and TPH at 1 cm intervals, and then sum the absolute values of the differences for each of the distributions. Sum the square of the
differences ($\Delta BAPH^2$ plus $\Delta TPH^2$) and then take the square root to reduce the measure of differences between each plot-pair to one number (Euclidean Distance). Fortunately this process can be easily implemented using a computer.

RESULTS

Seventeen structure classes were derived based on analyses of the 422 plots (Figure 3). Flat cumulative distributions correspond to “Uneven-aged” structures or perhaps more realistically, stands with a wide range of diameters. In contrast the cumulative distributions with steeper descents represent so called “Even-aged” stands, or perhaps more realistically stands with less variation in tree diameters. In general classes designated with a larger number tend to have more large trees. Classes 1 to 11 represent stands with less variability in average tree diameter. Class 12 is intermediate and classes 13 to 17 have more variability.

Does The Stand Structure Classification Really Work?

One validation of the classification is to compare the average plot statistics with their position on the stand density management diagram (Figure 4; Farnden, 1996). In general the groups derived using the cumulative distribution algorithm appear to be quite cohesive on the diagram, but there is some overlap. This occurs because the same average stand statistics can be produced by two different stem diameter distributions. Therefore the stand structure classification uses more information than the stand density management diagram in distinguishing one group of stands from another. Some of the plots exceed the maximum density line in the diagram because the “maximum line” is really based on a regression line that represents an average (maximum)

Figure 2. Cumulative distributions of basal area per hectare representing each of the 422 plots. Different colours represent different stand structure classes.
Figure 3. The average cumulative distributions for each of the seventeen structure classes representing basal area per hectare versus tree diameter at breast height (dbh).

density for a given average tree diameter per plot. Some plots may exceed this “average” as indicated in Figure 4.

**How Can Groups Be Distinguished From One Another?**

To begin with groups can be distinguished based on average stand statistics. Figure 5 illustrates the range of variability in total stems per hectare and basal area per hectare greater than 0 cm dbh associated with each stand structure class (1 to 17). For each stand structure there is a “box”, “whiskers” at both ends of the boxes, outliers (circles and stars) and a horizontal line in the middle of the box. The latter represents the median observation or 50\(^{th}\) percentile. Fifty percent of all the observations fall within the range of the ends of the boxes. As a rough guideline the ends of the whiskers describe the remaining observations, barring perhaps a few outliers that are noted as circles or stars. These graphs can be used as first cut to distinguishing amongst stand structures.

The figure describing trees per hectare tends to emphasize differences in the smaller size classes whereas the figure describing basal area does the opposite. It is clear that some of the classes are different than others because they contain many more small trees. Nevertheless the differences in basal area per hectare appear to be more significant as a first order determinate of whether a plot or a stand most likely belongs to one class versus another. Consideration must also be given to the actual distributions by diameter classes (See Table 1 for the standard definition of classes used throughout this paper. Also see Figures 6 and 7).
Figure 4. Stand structure classes with relatively narrow stand diameter distributions, classes 1 to 11 (so called “Even aged”), plotted on a lodgepole density management diagram (see Farnden, 1996).
Figure 5. Figures illustrate the range of variability in total stems per hectare (left) and basal area per hectare (right) greater than 0 cm dbh associated with each stand structure class (1 to 17).

Table 1. The diameter class numbers (indicated as DCLNO in figures to follow) are described along with the corresponding upper limit to the class (inclusive).

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<th>Class</th>
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<td>11</td>
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Figure 6. Stand tables (number of trees per hectare by diameter class) for each stand structure class (bold figures in grey boxes). The x-axis represents each of the diameter classes, 1 to 16. The y-axis represents the average trees area per hectare by diameter class up to a maximum of 2000 trees ha$^{-1}$ with major intervals indicated in increments of 200 trees ha$^{-1}$. The numbers inset into each figure (white boxes) describe the (average) total basal area per hectare.
Figure 7. Stock tables (basal area per hectare by diameter class) for each stand structure class (bold figures in grey boxes). The x-axis represents each of the diameter classes, 1 to 16. The y-axis represent the average basal area per hectare by diameter class up to a maximum of 12 m² ha⁻¹ with major intervals indicated in increments of 1 m² ha⁻¹. The numbers inset into each figure (white boxes) describe the (average) total basal area per hectare.
The Seventeen Classes

In the pages that follow (Figures 8 to 16) each of the stand structures are described by a pair of photographs and “box and whisker” diagrams describing the numbers of trees per hectare for small trees (diameter classes 1 to 4) and the basal areas per hectare for large trees (diameter classes 5 to 16). This allows for a more direct and intuitive basis for comparing the groups. The search for photographs to represent each of the classes was guided by the classification itself, not the other way round. It would have been very difficult to effectively and efficiently order the photographs or the plots (based on actual data) without first having the quantitatively derived classification.
Figure 8. Structures 1 (top) and 2 (bottom).
Figure 9. Structures 3 (top) and 4 (bottom).
Figure 10. Structures 5 (top) and 6 (bottom).
Figure 11. Structures 7 (top) and 8 (bottom).
Figure 12. Structures 9 (top) and 10 (bottom).
Figure 13. Structures 11 (top) and 12 (bottom).
Figure 14. Structures 13 (top) and 14 (bottom).
Figure 15. Structures 15 (top) and 16 (bottom).
Figure 16. Structure 17.

DISCUSSION

Rationale for The Approach

Cumulative distributions were used to develop the classification to avoid building a classification that is dependent on arbitrary subdivisions of the range of diameters. If instead some arbitrary diameter class boundaries were chosen to describe each plot, then changing the boundaries might result in a different classification. The use of cumulative distributions allow for diameter class boundaries to be set at different break-points without changing the nature of the classification.

Each of the cumulative distributions (TPH, BAPH) was normalized to represent numbers between 0 and 1 according to their rank (from lowest to highest), such that the maximum basal area per hectare and the maximum trees per hectare were each assigned a value of 1. This was necessary to ensure that each of the cumulative distributions received equal weight in determining the differences. When representing stands using trees per hectare, smaller trees tend to be more significant than larger trees (because the latter tend to be fewer in number). When representing stands using basal area per hectare, larger trees are more significant in the determinations of differences (because small trees make very little contribution to the total basal area). Both small and large trees are ultimately important for characterizing stand types, particularly when this information is to be used for forecasting growth and mortality in concert.
with designing silviculture regimen or in response to natural disturbances such as those caused by bark beetles.

Seventeen was subjectively chosen as the desired number of classes so as to increase the precision of the diameter distributions representing each class (relative to the currently available classifications), but to avoid increasing it by so much that it would be difficult for a person to reliability distinguish between different stand structures in the field without having to establish plots. Where stands are highly variable, it may be necessary to establish plots for accurately classifying stands. Such plots would be compiled to produce a stand-level tree list that can then be compared with the originally classified plots to determine the stand structure class. This kind of numerical comparison is made possible by the fact that the classification was derived initially using quantitative techniques, and these techniques are designed to ensure a maximum degree of within-group precision (between group separation).

Beyond the 17 groups, the decision to use cumulative distributions applied to only living trees, and beyond the details of normalization, no other subjectivity entered into the development of the classification.

Experience with the classification, demonstrates that it can be applied at either a plot or stand scale, with the full range of classes potentially being represented at both scales. Hence the classification can be used to represent different scales in support of forest management decisions. The main benefit of the classification is that it sets a standard for clear, consistent, and verifiable communication about what exactly is meant when somebody states that a stand belongs to a certain class.

This stand structure classification is species independent, i.e. it works regardless of species composition. This was done by design to ensure a broad level of applicability. To include species differences would demand more classes and more data. The methods used to build the classification could easily be extended to encompass species differences, and the resultant classes could be integrated with the original 17 classes used to maintain the more general structural subdivisions.

**Application to Inventories**

The stand structure classification has been used to impute tree lists for each and every polygon in two large inventories (each over 500,000 hectares) based on the relationships of polygon attributes (estimated through aerial photo interpretation) with plots of known location and stand structure class (Moss, 2004). Procedures were developed to account for considerable variation in the plot-level structure classifications when observed at the scale of inventory polygons. The results can be used for broad strategic planning purposes. Operational personnel can improve polygon delineations and the resultant stand structure class assignments to underwrite more reliable strategic and tactical plans.
Some Final Considerations

For areas that are managed as tree farms using clear-cutting and the establishment of even-aged plantations, stand structure classification is perhaps of lesser importance; traditional methods for characterizing stands may be sufficient. Where stands are more heterogeneous, stand structure classification as described herein is likely to add value to the current understanding of the nature of your forest.

Operational experience with the classification suggests that more elaborate descriptions of stand types may be required. For example, stands with an extensive number of large dead trees, due to bark beetles for example, would perhaps be classified as class 1 stands because the classification was built on the basis of living trees only. However, there is no reason why stands could not be classified using both dead plus live trees and then live trees only, and in so doing capture the transition of the stand from one class to another.

Another concern is that open stands are not well represented in the classification, due to a lack of samples in such types. This problem can be addressed by increasing the number of samples (or alternatively by simulating the development of stands thought to be) representative of these types. In the final analyses a whole new classification could be developed, or alternatively, the initial 17 groups could be kept in tact with further subdivisions made to a selected number of groups to accommodate such details.

The primary advantage of the 17 classes is that they are simple to learn and broadly applicable. The primary disadvantage is that they may still lack desired levels of precision for certain applications, particularly as it relates to characterizing small differences in predominantly young (short) stands. The classification could be extended to obtain increased precision, but it may be preferable to do so within the context of the 17 groups for the purpose of maintaining the generality at the upper levels of the classification.

CONCLUSION

How Does The Cumulative Distribution Approach Compare?

Is this stand structure classification better than other kinds of classification such as those that describe young, immature, mature and old for example? There are several advantages of this system of classification. First of all it is quantitatively derived rather than subjectively derived and therefore it is less susceptible to variable interpretation. Secondly, it is a classification developed for general purposes. It is designed to provide one system of classification where previously many might have been required, perhaps to speak about “old growth” in one context, and “high value stands” or “suitable mule deer winter range” in another. This makes it possible to better consider the interfaces between these issues using a common language rather than a disparate set of terms, the meaning of which are often confined to specialists. Thirdly, the classification is easy to use in the field so that where the establishment of additional plots might be too expensive for the purpose of determining the expected numbers of trees by diameter class, the stand structure classification can still be applied as a first approximation. This is faciliated with access to a variety of aids including a key (Farnden et al., 2003. Fourthly, plots can be
established in a stand and the resultant stand can be consistently classified into the correct group after compiling the data and undertaking a numerical comparison with the originally classified plots. Subjective assignments of stand structure class can thereby be verified based on a sample.

In summary cumulative distributions of the numbers of trees per hectare and basal areas per hectare can be used to identify different stands, much like finger prints can be used to identify different people, provided that there is a record of that stand in a database. This identification can be extended to include differences in species. The degree of differences between or similarities amongst two or more individuals can be assessed by estimating the absolute value of the differences in area under one set of distributions versus another. Such techniques can be applied at various scales of interpretation (plot, stand, landscape). In other words, the Cumulative Distribution Approach can be used to derive a single system of stand structure classification that works at a wide variety of scales. This provides a simpler, more consistent and verifiable means for communicating what is meant when we say that a stand belongs to structure class A versus B.

REFERENCES


