Tree crown structure in a mixed coniferous forest in México

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1. Abstract

Characterization of tree crown structure provides critical information to assess a variety of ecological conditions for multiple purposes and applications. Approaches to measuring tree crown structure and variability within multiple diameter distributions are particularly important in uneven-aged, multi-species natural stands. Results of using the "Weibull bimodal probability distribution function" to model diameter distributions of stands and crown index measurements to describe tree crown attributes and properties are presented and discussed. Specific patterns of values of these indices were found which suggest they have potential for use as indicators of crown structure complexity and variability across a wide spectrum of forest conditions and types. This research presents the results of indicators for tree crown structure in a mixed forest in Sierra Madre Oriental, México. Diameter, height, basal area and crown parameters of 504 trees were measured. Several crown indexes (crown width index, crown thickness index, crown spread ratio, crown projection area and crown surface area) were used. The variation of these indices is surprisingly high even within the same tree species. Conclusion of this research is that mixed forests present a specific structure, in accordance with its stem parameters, diameter distribution, and crown indices.

2. Background

The tree crown is one complement of net primary production and its dimensions reflect general tree health. Dense and large crowns are associated with potential growth rates. Sparse and small crowns can prove responsive to unfavorable site conditions (competition, moisture, diseases) (Kozlowski *et al.*, 1991). Tree crown shape varies from relatively dense conoid crown-shapes for conifers of an excurrent habitat to wide open shapes for many broad-leaved trees of a deliquescent habitat (Husch, *et al*., 2003). Tree crown research contributes to several key forest ecosystem attributes: biodiversity, productivity, forest management, forest environment, and wildlife (Laar and Akca, 1997; Avery and Burkhart, 2001).

The surface area of forest trees is a useful measurement for the study of rainfall interception, light transmission through forest canopies, forest litter accumulation, soil moisture loss, and transpiration rates (Husch, *et al*., 2003). The size of a tree crown is strongly correlated to tree growth. The crown displays the leaves to allow the capture of radiant energy for photosynthesis. Thus, measurement of a tree crown is often used to assist in the quantification of tree growth (Kozlowski *et al.*, 1991). The crown biomass and the quantity and quality of branch material are also of direct interest to ecological studies and research into the effects of trees on pollution. Nowadays, the knowledge concerning tree crown structure is important, in the sense that trees use this tree component as a source of absorption of carbon dioxide (Hussein, 2001).

The length of the live crown is determined as the height of the first branch or the first live branches (Nagel and Biging, 1996; Bachmann, 1998; Kramer, *et al.*, 1999). Taking into consideration the crown as a primary element in the vegetation development, several scientific studies relating to tree crown confirmation and growth have been undertaken to determine tree growth through models for tree crown profiles (Biging and Gill, 1997; Gadow, 1999; Gill *et al.*, 2000; Ebert and Eizele, 2001).

The objective of this research is to characterize tree crown structure in uneven-aged, mixed coniferous forests, through the application of tree dimensions (dbh, total height, basal area), diameter distribution (bimodal Weibull distribution) and crown indices (crown width, crown thickness index, crown spread ratio, crown projection area and crown surface area). This characterization of the site would be useful in different forest management applications, biodiversity, sustainability studies.

3. Methods and Description Areas

3.1. Study area

In recent decades, Mexico has promoted the protection of natural forests through the creation of protected areas and national parks. In 1998 the Cerro El Potosí was decreed as protected area, containing natural forests of high biological value and being located in the highest peaks (3,675 masl) of Northeastern Mexico. This mountainous area is located in the Sierra Madre Oriental. The area is located at an altitude of 3,100 meters above sea level.

3.2. Sample trees

The study area is in a mixed coniferous forest composed by *Abies vejari*, *Pseudotsuga menziesii*, *Pinus hartwegii* and *Pinus ayacahuite*. This uneven-aged stand contains 504 trees, with a mixture of species in a marked differentiation of strata. For each tree the diameter at the breast height (dbh), height (h), age (t), and basal area (g), as well as its spatial distribution, were measured.

3.3. Diameter distribution

To obtain the diametric distributions per species, the Weibull distribution was employed, being one of the most used in the forest area because of its relative flexibility, as well as being better adapted to uneven-aged and mixed forest (Maltamo, 1996; Nagel and Biging, 1996).

$$f(x) = \frac{\gamma}{\beta} * \left(\frac{x-\alpha}{\beta}\right)^{\gamma-1} * e\left(\frac{x-\alpha}{\beta}\right)^{\gamma}$$

Where $x =$ dbh, $\alpha =$ location parameter, $\beta =$ scale parameter, and $\gamma =$ shape parameter.

3.4. Measurements of tree crown

To characterize tree crown structure, measurements were taken in different sections of the crown in order to determine the shape and occupation area on an individual species, as well as on a complete site. In this sense the following parameters were determined: crown radius (*CR*), crown diameter (*CD*), crown length (*CL*), light crown length (*LCL*). Crown radius is needed in certain kinds of competition measurements (Gill *et al.*, 2000) and is defined in this study as the distance between the center of the bole and the four cardinal points. Crown diameter or crown width assessment is based on the measurement of two or four radii, and is usually defined as twice the radius. Crown length (Biging *et al.*, 1990) is defined as the distance between the apex of the tree and the base of the crown (CL = tree height – crown base). Live crown length is the distance between the apex and the base of the light crown (Fig. 1):

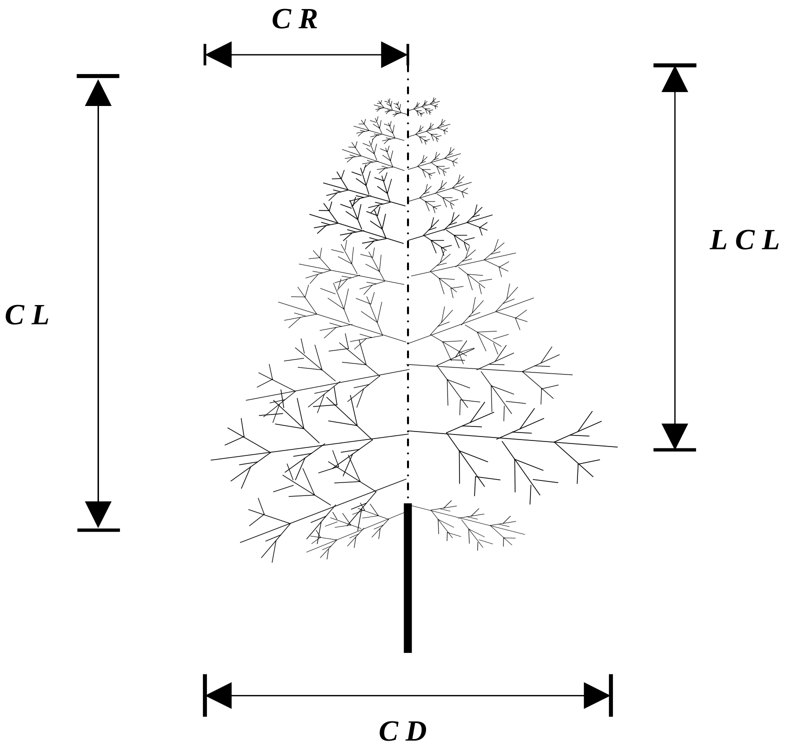

Fig. 1: Tree crown measurements

After tree crown parameters were measured, the following crown indices were calculated: Crown percentage is the length of the light crown length calculated as a percentage of the total tree height ($CR\% = 100 * CL/h$). Light crown percentage is the percentage of light crown length and crown length ($LCP\% = 100 * LCL/CL$). Crown thickness index is the ratio of the crown diameter and crown length ($CTI = CD/CL$). Crown spread ratio is the ratio between the crown diameter and the tree height and it is used when attempting to determine the shape of the crown ($CSR = CD/h$). The crown projection area is the surface occupied by the crown and is usually used as a measurement of stand density ($CPA = \pi/4 * CD$). The crown surface area is defined as the external surface area of the live crown. Normally it is assumed that the conifer crown can be represented either as a cone or as a paraboloid. The crown surface, based on the assumption of the paraboloid, is calculated as follows (Laar and Akca, 1997; Kramer, 1998; Jiménez, *et al.*, 2002):

$$CSA = \frac{\pi * CD}{12 * CL^2}\left[\left(4CL^2 + \frac{1}{4}CD^2\right)^{3/2}\right]$$

4. Results and discussion

4.1 Size structure

Analysis of dendrometric parameters to understand the stand characteristics was made. There was a similarity between the tree number of most species: *Pinus ayacahuite* (124 stems/hectare), *Abies vejari* (120 stems/hectare) and *Pseudotsuga menziesii* (102 stems/hectare), except for *Pinus hartwegii* (60 stems/hectare). However, an affinity was discovered in the values of the basal area for *Pinus ayacahuite*, *Pinus hartwegii* and *Pseudotsuga menziesii.* Despite the fact that *Abies vejari* showed a higher tree number, its basal area only represented 12% of the total basal area. This low value occurred as a result that *Abies vejari* is younger and has an average diameter of

12.5 cm and an average height of 7.9 m. *Pseudotsuga menziesii* showed the greatest dispersion in diameter with 77.2%. In general, there was a high variability between all the species with respect to age (14-126 years), diameter (5-65.4 cm) and height (2.2-22.4 m). This high variability in age, height, and diameter of the species was expected for a mixed and uneven-aged stand.

4.2 Diameter distribution

We analyzed diameter distribution of the species to locate the tree position within the stand. To complete this objective, the individuals were arranged by diameter classes of 10 cm in order to separate the individuals by ranges. In general, we observed that most trees ranged in diameters between 10-40 cm, with a large proportion belonging to the 10 and 20 cm (398 trees) with only 106 trees remaining in the following categories. *Abies vejari* was found in the 10 and 20 cm diameter classes (143 trees), as were *Pseudotsuga menziesii, Pinus ayacahuite* and *Pinus hartwegii* showed a similarity in both 20 and 50 cm diameter classes.

In order to determine the diameter distribution applicable to all species we used the Weibull distribution (Laar & Akca,1997). However in its natural state, the stand showed a bimodal type distribution, resulting in a typical structure with two subpopulations. We show that *Abies vejari, Pseudotsuga menziesii* and *Pinus hartwegii* have a higher number of individuals in the minor distribution class. However, *Pinus hartwegii* showed a similar bimodal distribution. At the site level, 73% of the trees were located in the lower strata and only 27% of them in the higher strata, showing a clear bimodal distribution.

In order to process vertical differentiation within the stand structure, Wenk (1996) suggested calculating the parameters of the function of each strata. This study employed a method for describing bimodal diametric distributions using estimates of a maximum and minimum stand diameter (Hessenmöller and Gadow, 2000). Thus, for the mixed conifer forest the following bimodal Weibull distribution results:

$$f(x) = g * f_u(x) + (1-g) * f_o(x)$$

Where $f_u(x)$ and $f_o(x)$ describe the respective diametric functions regarding the higher and lower forest strata and *g* is the linking parameter between both functions.

4.3 Crown analysis

Following the diameter analysis, we proceeded to separate the trees into Height Zones in accordance with Pretzsch (1996), where the greatest height of the site was recorded (22.4 m). The study site was divided into two strata: Height Zone I and Height Zone II. It shows the trees by species and by Height Zones, 75% (376 stem) corresponding to the individuals in Height Zone II, and only 25% (128 stem) in Height Zone I.

In the predominant and dominant trees strata (Height Zone I), *Pinus ayacahuite* and *Pinus hartwegii* showed a remarkable similarity in their stem dimensions (*dbh, h, t*). With respect to the relation dbh/h, we observed that they presented a lower value (41-42), which is evidence of the stability of the species in this site. *Abies vejari* and *Pseudotsuga menziesii* showed a greater variability in their dendrometrical parameters, as well as an increase in their stabilizing values (51-61). This is due to the fact that they are shade-tolerant species, and for this reason their development is slower in their primary phases and with greater competition, which explains the lack of a positive stable relationship does not exist. However, in Height Zone II, the shade-tolerant species showed a greater similarity in diameter, height, and age values, thus suggesting a greater stability.

The definition of live crown is important to calculate the crown length, crown percentage, crown thickness index and crown surface area. In this case, the base of live crown was defined as the height of the last live branch. It shows in general that, in the upper stratum, the crown percentage covers 53% of the tree, while in the lower stratum it covers 73%. At a species level, it was observed in Height Zone I that crown percentage decreases while age increases (*Pinus hartwegii t* = 73; *CR%* = 45%, *Abies vejari t* = 47; *CR%* = 62). This is result of crown percentage decreases while the tree keeps growing. However, in Height Zone II there was a great similarity between the age (28-31 years) and CR% (71-78%) values, presenting no difference between the species, perhaps they were located underneath the canopy of Height Zone I.

In order to characterize the light crown length (*LCL*) the height of the widest part of the crown was measured, and to calculate the light crown percentage (*LCP%*). In general, there was no differentiation of the *LCP%* (75%) between the two Height Zones. At the species level, *Abies vejari* had the highest *LCP%* (I = 96%; II = 90%), meaning, practically, that a high percentage of the light crown belongs to the complete crown. *Pseudotsuga menziesii* also had a high percentage of light crown (87%). This is perhaps because both species are tolerant to light. However, for both pine species, there was a smaller percentage of *LCP%* (I = 60-67%; II = 61-65%). Table 6 shows crown diameter (CD), crown thickness index (*CTI*), crown spread ratio (*CSR*), crown projection area (*CPA*) and crown surface area (*CSA*). In Height Zone II no considerable difference was observed among these parameters, however, *Pinus hartwegii* showed a slighter tendency in comparison to the other species. In turn, *Abies vejari* showed the same tendency in Strata I. In the same Height Zone I, pine species, while having similar values in age and stem dimensions, showed a differentiation in their crown variables.

The crown thickness index showed a certain differentiation between the dominant trees (0.74) and the suppressed trees (0.63). This differentiation is probability a result of the trees in Height Zone I experiencing less competition, especially *Abies vejari* (0.51) and *Pseudotsuga menziesii* (0.61) which have a conoid crown, in contrast to pine trees which have a paraboloidal aspect. There was a general level a differentiation of crown spread ratio between both zones (I = 0.37, II = 0.45), but at a species level, no major differences were found within the strata.

Pinus hartwegii showed a higher CPA (16%) than *Pinus ayacahuite (*that has a wider crown diameter). The highest CPA was held by the species in Height Zone I, ranging between the 14.91 and 33.90 m^2. In turn, the crown surface area (11%) was lower for *Pinus hartwegii*. This is because it was 1.5 m (18%) shorter than *Pinus ayacahuite*. The maximum CSA was found for *Pseudotsuga menziesii* (102.97 m^2) and *Pinus ayacahuite* (102.13 m^2), due to the presence of a greater *CL* (8.9 m and 8.2 m). At the light crown surface level, it was observed that the species with the highest value, in both zones, were *Abies vejari* and *Pseudotsuga menziesii*, due to having their crowns of a conoid and excurrent type.

5. Conclusion and Recommendations

In agreement with the heterogeneous structure of this mixed and uneven-aged stand, there was a great variability in stem dimensions and crown parameters, not only at a site level, but also in the species that are found in the ecosystem. *Abies vejari* was the species showing the lowest average age (32 years) and *Pinus hartwegii* was the one presenting the highest average age (51 years). Despite this, *Pinus ayacahuite* showed a wider dispersion range (15-126 years), which is expected in an uneven-aged ecosystem. In turn, *Pinus hartwegii* had the widest average diameter (55 cm), and *Pseudotsuga menziesii* had the widest range of variability (cv%=77.2%). *Pinus hartwegii* with 10.6 m was the tallest species with a range between 2.3-22.4 m.

A large discrepancy was observed in tree distribution per species. The shade-tolerant species - *Abies vejari* and *Pseudotsuga menziesii* - had 74% and 66% of their individuals in 10 cm diameter classes; while the light-tolerant species – *Pinus ayacahuite* and *Pinus hartwegii* – had 55% and 47% of their trees in this diameter class.

There was a bimodal type Weibull distribution for the tree species. *Abies vejari, Pseudotsuga menziesii* and *Pinus ayacahuite* showed a higher slope in the first diameter classes, due to a larger number of trees, while *Pinus hartwegii* showed a similar tendency among the higher and lower diameter classes, which resulted in a similar curve slope. In general, there was a good adjustment in the bimodal Weibull distribution for all species. The forest ecosystem had two strata in vertical structure with shade-tolerant and light tolerant species.

One of the important objectives in this research was the analysis of the crown parameters (crown radius, crown diameter, crown length and light crown length). With these variables, the crown indices were defined: crown percentage, light crown percentage, crown thickness index, crown spread ratio, crown projection area, and crown surface area. There was a great heterogeneity in the values corresponding to the crown indices (*CL, CTI, CSR, CPA* and *CSA*) in Height Zone I and Height Zone II; the discrepancy among the species within each of Height Zones was greater.

Crown thickness index showed a great differentiation between dominant and suppressed trees. There was a certain differentiation of crown spread ratio between Height Zone I and II, but no major differences within the strata were found.

Uneven-aged mixed stands present a specific structure, in agreement with its stem parameters, diameter distribution, and crown parameters and indices. These tree crown structure indicators have a high value in forest ecosystem management, where the forest structure is considered a high priority.

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