DIVERSITY AND STRUCTURE OF FOREST ECOSYSTEMS AS A TOOL FOR SUSTAINABLE DEVELOPMENT IN MEXICO

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- ABSTRACT

Characterization of forest ecosystems structure must be based on quantitative indices that allow objective analysis of human influences or natural succession processes. The objective of this paper is the compilation of diverse quantitative variables to describe structural attributes from the arboreal stratum of the ecosystem, as well as different methods of forest inventory to obtain such indices. For the evaluation of the species structure the indices of Shannon *H',* species profile *A*, segregation *S* of Pielou and the species mingling index M_i are discussed. The agregation index *R* of Clark & Evans and the contagion index W_i, were included in order to describe the horizontal structure of the ecosystem. Finally, for the characterization of the dimensional structure, the homogenity coefficient *H* and the indices of diameter differentiation TD_i and height differentiation TH_i were analyzed.

RESUMEN

La descripción de la estructura del estrato arbóreo de ecosistemas forestales debe basarse en índices cuantitativos que permitan analizar objetivamente influencias antropogénicas o procesos de sucesión natural. El objeto de este trabajo es la recopilación de diversas variables cuantitativas para la caracterización de los atributos estructurales del estrato arbóreo de los ecosistemas, así como diferentes métodos de inventario forestal para su obtención. Para la evaluación de la estructura de especies se discuten los índices de Shannon *H'*, el perfil de especies *A,* el índices de segregación *S* de Pielou y el de mezcla de especies *Mi*. El índice de agregación *R* de Clark & Evans y el índice de ángulos W_i se incluyen para la descripción de la estructura horizontal del ecosistema. Finalmente, para la caracterización de la estructura dimensional se analiza el coeficiente de homogeneidad *H* y los índices de diferenciación diamétrica *TDi* y de diferenciación en altura *THi*.

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Introduction

One of the aims of the forest management is the search for new inventory and planning methods of the forest ecosystems, particularly in an era in which discussions on the conservation and promotion of biodiversity are rivaled, by the increase in the demand of forest products. A gradual transformation of medium- and longterm silvicultural policy is taking place with the abolishment of even-aged pure forests and a greater preference of uneven-aged mixed forests. For such ecosystems indices that quantitatively characterize the structure and diversity are required. Uneven-aged forest management has become an important factor significantly influencing forestry research. The challenge is to obtain the new indicators of sustainability of forest resources.

The indices for characterizing the structure and diversity of the ecosystems allow a better reproduction of the condition of the forest in a given moment and of its evolution in time. Such indices would have to be considered in addition to conventional variables such as diameter, height, basal area, volume, age and density, in order to achieve a better description of the stands.

The objective of this work is to discuss variables for the quantitative description of the structure and diversity of forest ecosystems. The characterization levels considered include species diversity and structure, spatial structure and the dimensional diversity of the ecosystem. Case studies results of the application of such indices in mexican forests are presented (Aguirre *et al*., 1998, 2001; Jiménez *et al*. 1998; Kramer *et al.* 1999).

SPECIES DIVERSITY AND STRUCTURE

Index *H'* of Shannon

The Shannon index (Shannon, 1948) is one of the most employed variables for the estimation of species diversity; for its determination is employed the formulation:

$$H' = -\sum_{i=1}^{S} p_i \cdot \ln(p_i)$$

S = number of present species
pi = proportion of the species $pi = n_i / N$
N_i= number of individuals of the species i
N = total number of trees

As an example of the application of this index the following types of ecosystems with different species composition are presented. This conditions were found in the School–Forest of the University of Nuevo León:

- 100% *Pinus pseudostrobus* ; *H'* = 0.00
- 80% *P. pseudostrobus* , 20% *Quercus rysophylla*; *H'* = 0.50
- 50% *P. pseudostrobus* , 20% *Q. rysophylla*; *H'* = 0.69
- 70% *P. pseudostrobus* , 20% *Q. rysophylla*; 10% *Juniperus flaccida*; *H'* = 0.80

The value *H'* increases according as a greater number of species occurs and the individuals proportion of the species is more homogeneous. *H'* depends not only on the number of species present in an ecosystem, but on the frequency with which they are represented.

Species Profile *A*

To characterize the vertical structure of the species of a forest ecosystem, Pretzsch (1996) based on the index of Shannon, developed the variable profile of species *A.*

$$A = -\sum_{i=1}^{S} \sum_{j=1}^{Z} p_{ij} \cdot \ln(p_{ij})$$

S = number of present species
Z = number of height strata (3 in this case)

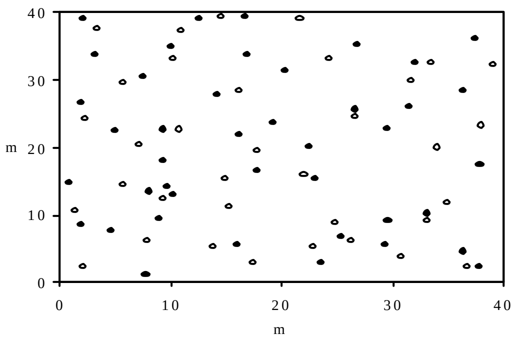
P_{ij} = proportion of species in the height strata $p_{ij} = n_{ij} / N$

n_{ij} = number of individuals of the species i in the stratum j
N = total number of trees

Pretzsch defines three strata for the application of the index *A*; stratum I comprises from 80% to 100% of the maximum height of the trees; stratum II 50% to 80% and stratum III 0 to 50%. Differing from the index of Shannon, index *A* characterizes the location of the species in different height strata. *A* takes values between 0 and a maximum value *A*. A value *A* of 0 means that the stand consists of only one species that occurs in one sole stratum. $A_{maximum}$ is obtained when all of the species occur in the same proportion in the stand as well as in the different strata. In an ecosystem constituted by 11 arboreal species, values of *A* = 2.07 and $A_{maximum}$ = 3.50 were obtained.

Segregation Index *S* of Pielou

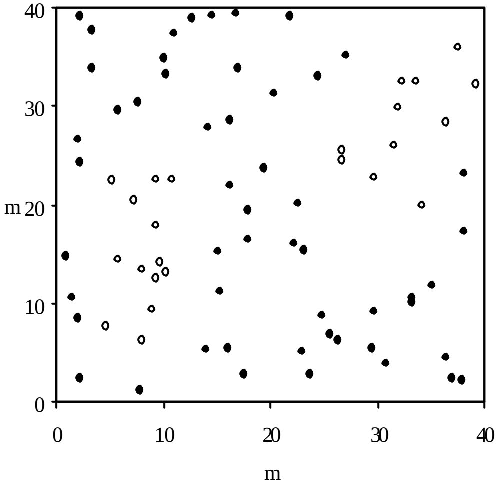
The segregation index *S* of Pielou (1961) describes the combination or mingling of two species, that is, the spatial classification of a species in relation to the other. This index is based on the ratio between the observed and the expected number of mixed pairs. A "mixed pair" denotes a tree of one species (1) having a tree of the opposite species (2) as its nearest neighbour. *S* takes on a negative value when there is a mutual attraction among the two species. A value of zero indicates that the distribution of the species are independient of each other. *S* greater than zero corresponds to a segregation, this is, spatial separation of the species. In figure 1 two fractions of ecosystems with different distribution of the species are presented. In the area a) *S* = - 0.72, by it the species pres ent an evident association; opposite to the foregoing, in the area b) with a value of S = 0.79, a clear segregation of the species is observed.



a) ● Species A
○ Species B

a) *S* = - 0.7225
b) *S* = 0.7905

Fig. 1**:** Index of segregation *S* of Pielou for two fractions of ecosystems.



Species Mingling Index M_i

The species mingling index Mi is defined for a reference tree and its three nearest neighbours as the relative proportion of neighbouring trees of different species (Füldner, 1995). This index was developed in order to infer information on the vertical and horizontal distribution from the species and is given by:

$$M_i = \frac{1}{n}\sum_{j=1}^{n} m_{ij}$$

m_{ij} takes a value 0 when the neighbour belongs to the same species of the reference tree; otherwise it has a value of 1.

Since m_{ij} it is a discrete binary variable, M_i can take the following values:

0.0 when all the individuals of the group (four) belong to the same species;
0.33 when one of the neighbours of the reference tree belongs to other species;
0.67 if two of the neighbouring trees belong to other species and
1.00 if the neighbouring three of the reference tree belong to different species

The graph 2 shows species mingling values for a stand of *Pinus pseudostrobus*, *Juniperus flaccida* and *Quercus ryzophylla*. The values for the three species are presented separately. *P. pseudostrobus* is found in pure groups (*Mi* = 0) as well as surrounded of one or more individuals of other species (Mi ≥ 0.33*). J. flaccida* and *Q. ryzophylla* are presented mainly with neighbours of different species. *J. flaccida* individuals are normaly isolated from coespecifics.

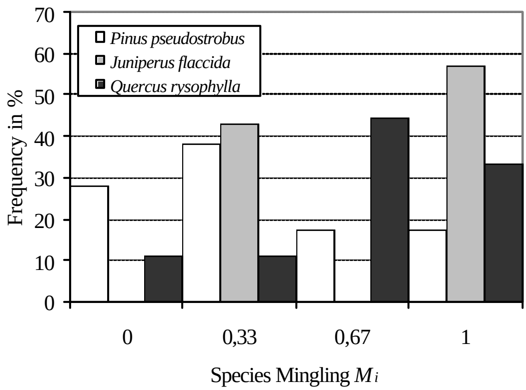


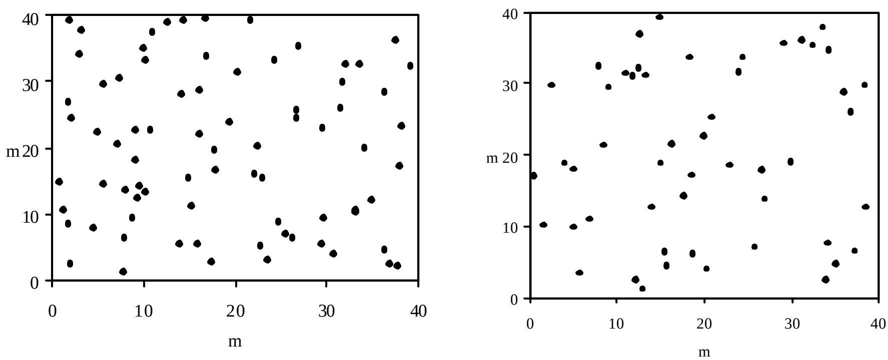
Fig. 2: Distribution of the species mingling index in a mixed ecosystem.

SPATIAL STRUCTURE

Index of Aggregation *R* of Clark & Evans.

The aggregation index *R* of Clark & Evans (1954) describes the degree of regularity in the distribution of tree positions. This index is based on the relationships of distance between neighboring trees and, although widely used in botany and vegetation science, is rather unknown in the practice of forestry. It is simply calculated as the ratio between the observed and expected average distance for a random distribution between neighbouring trees. *R* takes on a value of 1 if the distribution of tree positions is random and trends toward zero with increasing aggregation. The maximun possible value is 2.15. Values greater than 1 indicate increasing tendency to regularity.

An example is presented in figure 3, showing the distribution of the trees in fractions of two stands of pine-oak in Northeastern Mexico's. Stand a) has a value of *R* = 0.98, that indicates a random distribution of the trees. In stand b) *R* is 0.89, thus presents a distribution with trend to the conformation of groups.



a) *R* = 0.98
b) *R* = 0.89

Fig. 3: Index of Clark & Evans for two ecosystems with different horizontal structure.

Contagion Index *Wi*

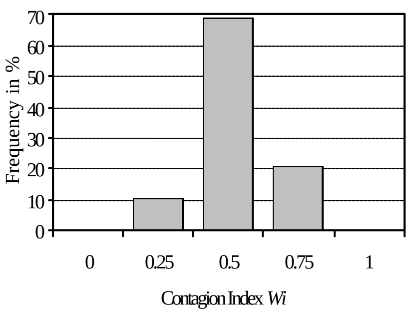
The contagion index *Wi* (Gadow *et al*., 1998) describes the regularity of the distribution of the neighboring trees to a reference tree. The determination of this index is based on the measurement of the angles between two neighbours of the reference tree and its comparison with a standard angle. The contagion index *Wi* is then defined by the proportion of the smaller angles α to the standard angle $\alpha_0 = 90º$. *Wi* is calculated as follows:

$$Wi = \frac{1}{n}\sum_{j=1}^{n} w_{ij}$$

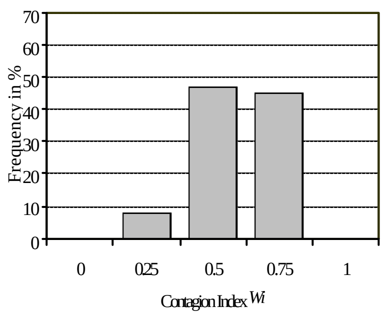
w_{ij} has a value of 1 when the angle between two next neighboring trees is smaller than the standard angle α_0, otherwise it takes a value of 0.

If n = 4, W_i can present the following values:
0.0 if none of the angles is smaller to standard angle,
0.25 if one of the angles is smaller to standard angle,
0.50 when two of the angles α are smaller to standard angle,
0.75 if three of the angles α are smaller to standard angle, and
1.0 when the four angles α are smaller to standard angle.

Values of $\overline{W}$ of 0.5 correspond to a random distribution of the trees, those greater to this value represent a grouping trend. Smaller values indicate a trend towards regularity. For the ecosystems of the graphic $\overline{W}$ = 0.53 indicates a random distribution of the trees while $\overline{W}$ = 0.59 corresponds to a trend to a grouping of the trees.



a) $\overline{W}$ = 0.53



b) $\overline{W}$ = 0.59

Fig. 5: Distribution of the trees in the contagion index *Wi*, in two stands with different horizontal distribution.

DIMENSIONAL DIVERSITY

Homogeneity coefficient *H*

The homogeneity of a stand can easily be described through the employment of the homogeneity coefficient (*H*) of De Camino (1996). *H* is expressed through the percentual relationship between number of trees and volume by diameter classes. In a totally homogeneous forest all the trees have the same volume; in heterogeneous one a high percentage of trees represent a small proportion of volume, while few individuals contribute with the greater proportion of the volume.

The graphic 6 shows the homogeneity coefficients (*H*) obtained in the unthinned and thinned fractions of a stand of *Pinus cooperi* and *P. leiophylla*, as well as the corresponding Lorenz curves. A greater homogeneity of the thinned area is observed here, the *H* value is greater (6.03) and the Lorenz curve is found accordingly nearer the reference line.

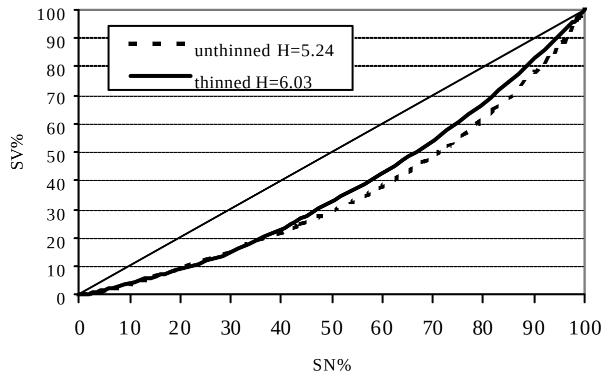


Fig. 6: Homogeneity coefficients and Lorenz curve for the unthinned and thinned fractions of an ecosystem.

Dimension Differentiation Indices

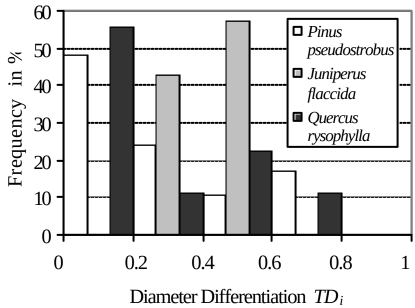
The dimension differentiation indices describe the relationship between a given tree and its nearest neighbor and are defined by the quotient between a dimensional variable of the smaller tree and the corresponding of the bigger tree, substracted form 1.

The diameter differentiation *TDi* (Füldner, 1995), for example, is obtained from the relationship of the diameters from neighboring trees deducted from 1. A *TDi* value of 0 means that both trees have the same diameter. As the difference of the diameters increases, the value of *TDi* also grows.

Other dimensional variables may similary be employed in addition to the diameter differentiation *TDi*. These would include, for example, the indices of height differentiation *THi*, and of crown cover differentiation *TKSi* (Aguirre *et al*., 1998).

Figure 7 shows the distribution of the trees of a mixed forest in the classes of diameter differentiation 0.0-0.2, 0.2-0.4, etc. For *Pinus pseudostrobus* a greater proportion of the trees present a scarce diameter differentiation with respect to their neighbours (class 0.0-0.2); *Quercus rysophylla* shows a similar frequency, which has more than half of the cases with a diameter difference to their next neighbor smaller than 20%. *Juniperus flaccida* behaved differently in that the greater proportion of trees shows differences of diameter between 40 and 60% (class 0.4-0.6).

The frequency of height differentiation classes for the previous species is observed in here. *Pinus pseudostrobus* presents smaller height differentiation that the rest of the species, about 60% of the trees has values smaller than 0.2. In contrast to diameter differentiation, *Juniperus flaccida* showed a minor height differentiation, while for *Quercus rysophylla* the tree frequency in the class 0.6-0.8 is increased, this is, more than 20% of the trees showed a height differentiation greater than 60%.



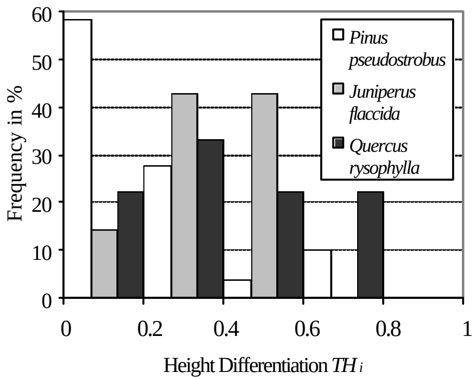


Fig. 7: Distribution of the trees in the classes of diameter and height differentiation.

CONCLUDING REMARKS

The indices considered in this work constitute an alternative for the evaluation and monitoring of the structure and diversity of forest ecosystems on quantitative grounds. The application of such indices in an integral method of forest inventory allows a better description and reproduction of the ecosystems, as well as the development of indicators of sustainability of forest resources management.

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