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Article

Distribución espacial de *Pinus oocarpa* Schiede ex Schltdl. mediante la estimación de la densidad *Kernel*

Spatial distribution of *Pinus oocarpa* Schiede ex Schltdl. through estimating Kernel density

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Resumen

En el estado de Chiapas, *Pinus oocarpa* se distribuye ampliamente a lo largo de la Sierra Madre de Chiapas, específicamente, en las subprovincias de la Depresión Central, la Altiplanicie Central y las Montañas de Oriente. En el presente trabajo, se analizó la distribución espacial de esta especie a través del análisis de la densidad *Kernel*, para lo cual se empleó información generada por el Inventario Nacional Forestal y de Suelos. La comparación entre los diferentes mapas con la distribución de *P. oocarpa* se realizó mediante la definición de una matriz de confusión para cada uno de ellos, las cuales se basaron en una clasificación binaria. La exactitud de los datos obtenidos se determinó con el coeficiente *Kappa*. De acuerdo con la distribución definida por la estimación de la densidad *Kernel*, se confirma que *P. oocarpa* se ubica, básicamente, a lo largo de la Sierra Madre de Chiapas y la Altiplanicie Central, lo que coincide, en general, con la mayoría de las ilustraciones de su distribución geográfica. La metodología propuesta se puede emplear en otras regiones donde se cuente con información de inventarios forestales (nacionales, estatales, regionales, de manejo, etcétera), solo hay que limitar la definición de la distribución del taxon de interés al área que cubre el diseño de muestreo.

Palabras clave: Ancho de banda, coeficiente *Kappa*, interpolación, Inventario Nacional Forestal y de Suelos, matriz de confusión, superficies continuas.

Abstract

In the state of *Chiapas*, the species *Pinus oocarpa* is widely distributed throughout the *Sierra Madre de Chiapas*, specifically in the subprovinces of the central depression, the central highlands and the eastern mountains. In the present work the spatial distribution of this species was analyzed through Kernel density analysis, using information generated by the National Inventory of Forests and Soils of Mexico (INFyS), the proposed alternative process estimates the spatial distribution of this species through Kernel density analysis. For this reason, the presence of the species can allegedly be represented as a series of georeferenced events, which occur differentially along a given region, determining spatial variations in their density. To make the comparison between the different maps that present the distribution of *P. oocarpa*, a confusion matrix was defined for each one of the maps, which were based on a binary classification. The distribution defined through the Kernel density estimation confirms that *P. oocarpa* is located basically along the *Sierra Madre of Chiapas* and the Central High Plateau, generally agreeing with most of the illustrations of the geographical distribution of this species. The methodology proposed herein can be used in other regions where information from forest inventories (at national, state, region, or management level) is available, by limiting the definition of the distribution of the species of interest to the area covered by the sampling design.

Key words: Bandwidth, Kappa coefficient, interpolation, National Forest and Soil Inventory, confusion matrix, continuous surfaces.

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Introduction

The genus *Pinus* is represented by approximately 100 species in the world (Alba-López *et al.*, 2003). Its natural distribution covers the Arctic and sub-Arctic regions of North America and Eurasia; its largest diversification center is located in the northern and central region of the American continent —with approximately 70 taxa (Farjon *et al.*, 1997; Price *et al.*, 1998)—, in which Mexico houses the largest number of species in the world, naturally located in all the states of the country, except for *Yucatán* (Martínez, 1992). Nevertheless, the surfaces of pine forests in Mexico have dwindled, a situation that has called for the implementation of strategies for their restoration and promotion based mainly on the collection of seeds, and the production and planting of seedlings (Conafor, 2010). The success of these activities, however, depends upon the most accurate possible knowledge of the spatial distribution of the taxa of interest, as well as upon the estimation of the seed collection potential, the environmental conditions in which the species is located, and the best areas for its growth.

Important studies have been carried out on the ecogeography and biogeography of pine taxa (Vargas, 2008); however, greater geographical precision is required in order to determine their distribution. Especially, considering that this is determined not only by their adaptation to the environment of by their evolutionary history, but also by the impact of human activities in the last centuries. Therefore, it is necessary to locate the pine species in order to measure their present surface area; their environmental conditions must be characterized, and the areas with disturbances, potential areas for reforestation and promotion, and others, must be located, since no updated maps allowing to know the current and potential location of pine trees are available.

Specifically in the state of *Chiapas*, where the study documented herein was carried out, the physiographic regions where pines grow are, according to Mullerried (1957): the Central High Plateau (CHP), and the *Sierra Madre of Chiapas* (SMC) (Alba-López *et al.*, 2003), which reportedly harbor approximately 12 pine species: *P. ayacahuite* Ehrenb. ex Schltdl., *P.*

michoacana Martínez, *P. hartwegi* Lindl., *P. maximinoi, P. montezumae* Lamb., *P. oocarpa* Schiede ex Schltdl., *P. patula* Schiede ex Schltdl. & Cham., *P. pseudostrobus* Lindl., *P. oocarpa* var. *ochoterenae* Martínez, *P. chiapensis* (Martínez) Andresen, *P. oaxacana* Mirov. and *P. teocote* Schiede ex Schltdl. & Cham. (Breedlove, 1986; Perry, 1991; Martínez, 1992; Farjon *et al*., 1997; Conafor, 2011).

Specifically, *P. oocarpa* is distributed along the *Sierra Madre of Chiapas*, in the subprovinces of the Central Depression, the CHP and the eastern mountains (Gutiérrez *et al*., 2010), covering a wide range of altitudes, in an uneven orography with a long geological history; this allows for a huge variety of ecological conditions and, therefore, a large biological diversity (Breedlove, 1986; Ceballos *et al.*, 1998). Nevertheless, there are few publications that illustrate the geographical distribution of this species (Figure 1), mainly at a national scale (Mirov, 1955; Sánchez and Huguet, 1959; Eguiluz-Piedra, 1985; Instituto Nacional de Investigaciones Forestales, 1974; FAO, 1977; Perry, 1991; Farjon *et al*., 1997; Howell and Mathiasen, 2004).

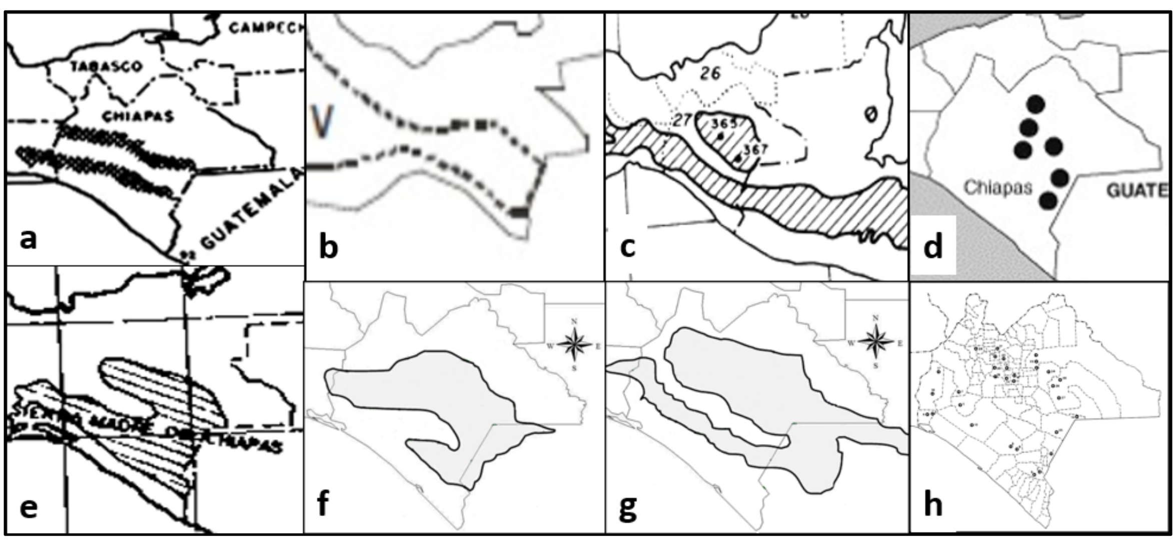


Figure 1. History of the general location of the genus *Pinus* in *Chiapas*: a. Mirov, 1955; b. Eguiluz-Piedra, 1985; c. Instituto Nacional de Investigaciones Forestales, 1974; d. Howell y Mathiasen, 2004; e. Sánchez y Huguet, 1959; f. Perry, 1991; g. Farjon *et al*., 1997; h. FAO, 1978.

On the other hand, certain works also include more localized maps of the *P. oocarpa* populations, in relation to seed collection (Sáenz-Romero *et al.*, 2006) or to the presence of certain pests (Domínguez-Sánchez *et al.*, 2008). Conventionally, the geographical distribution of *P. oocarpa* is represented by means of roughly outlined areas.

Within this context, the purpose of this work was to define the spatial distribution of *P. oocarpa* in the state of *Chiapas*, through Kernel density estimation, using information collected at the National Inventory of Forests and Soils (INFyS) for the 2004-2010 period (Conafor, 2011).

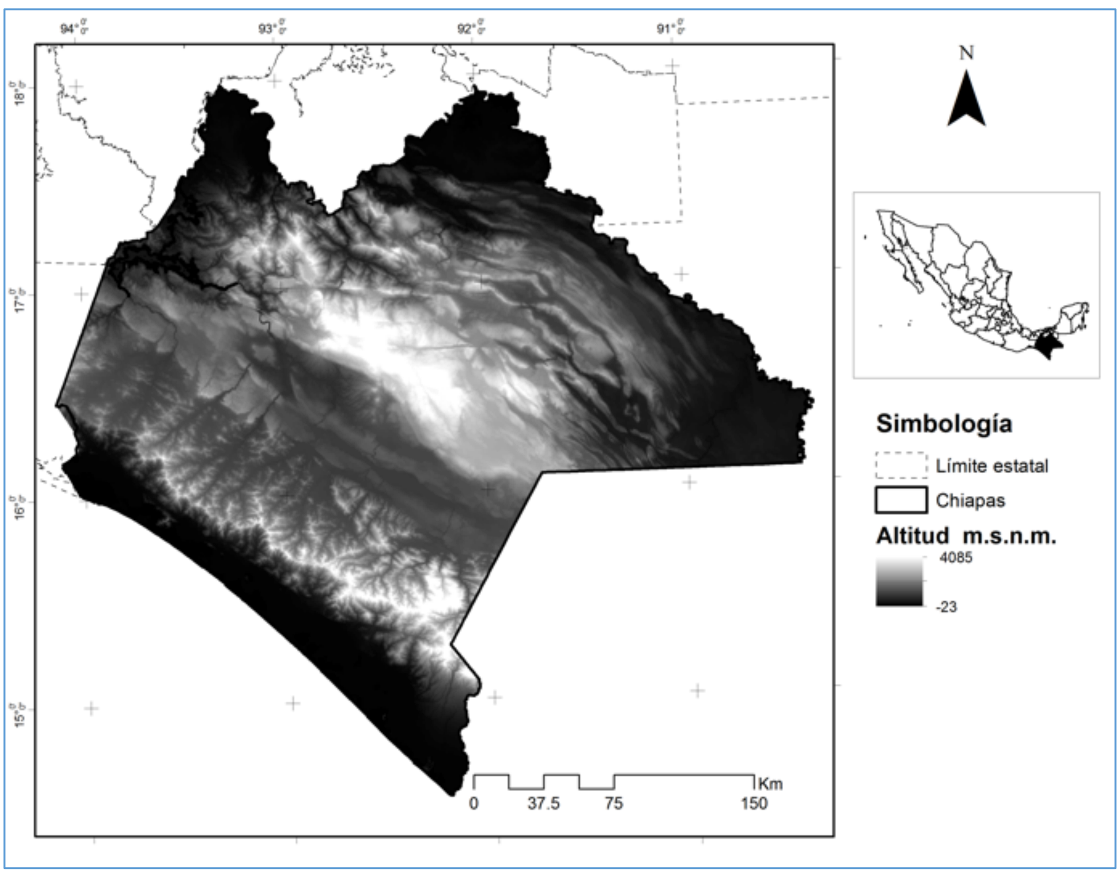
Materials and Methods

Description of *Pinus oocarpa*

Pinus oocarpa has the following synonyms: *P. tecunumanii* F. Schwerdtf. and *P. oocarpoides* Lindl. ex Loudon; in *Chiapas*, it is known as *ocote*, *pino trompillo*, *pino alazán*, and *pino bola*. This tree reaches a height of 30 to 35 m, with a normal diameter of up to 125 cm (Farjon *et al.*, 1997). Its needles are straight and rigid, generally grouped in fascicles of five (rarely of 3 or 4), and measure 17 to 30 cm in length, and 0.8 to 1.4 mm in width. Its cones are solitary or occur in whorls of up to four, ovoid in shape when open and globular when closed; they are 3 to 10 cm long and 3 to 12 cm wide (Farjon *et al.*, 1997). This species grows within an altitude range of 200 to 2 700 m, in sites with a minimum temperature of -1 °C and a maximum temperature of 40 °C; specifically in the state of *Chiapas*, it is found at an altitude between 401 and 2 401 masl; at a minimum, semi-cold temperature of 5 °C and a maximum, very warm temperature of 38 °C, in a warm or temperate climate with minimum annual precipitations of 600 mm and maximum annual precipitations of 3 500 mm (Gutiérrez *et al.*, 2010). In the state, it grows on soils that are very rich in organic matter and nutrients, highly susceptible to erosion, with volcanic ashes, and with a high content of clay, formed from recent alluvial materials (Martínez, 1992). *P. oocarpa* is characterized by a rapid growth under semi-tropical conditions and is generally used for sawn wood and cellulose, but also as firewood.

Study area

The study area is located in the state of *Chiapas*, in southeastern Mexico, between the coordinates 14°31’37.41” and 17°59’26.6” N, and 90°22’8.20” and 94°9’11.64” W (Figure 2).



Simbología = Symbology; *Límite estatal* = State limit; *Altitud* = Altitude.

Figure 2. Location and altitude range of the state of *Chiapas*.

INFyS clusters

The present study is based on data provided by the INFyS for the state of *Chiapas*, where 1 590 clusters were established (Figure 3); of these, 125 (8 %), located mainly in the SMC and the CHP, registered nine species of pines. The greatest diversity of genera is observed in 42 municipalities, notably in *Comitán de Domínguez, La Concordia*, and *Ocosingo*. Based on this information, the clusters where *P. oocarpa* are present were selected.

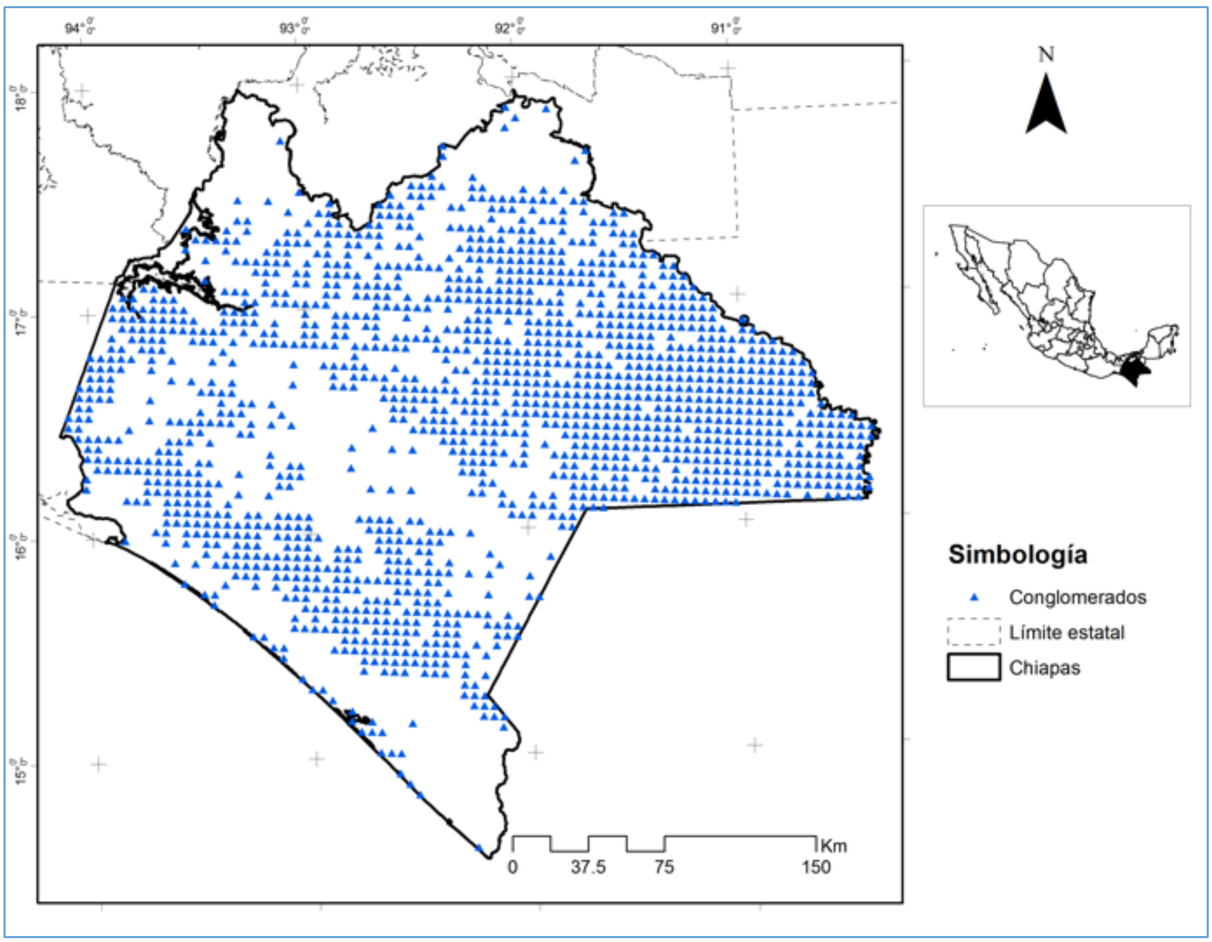


Figure 3. Clusters of the National Inventory of Forests and Soils in the state of *Chiapas* (Conafor, 2010).

Kernel density estimation

It is assumed that the existence of a species can be represented as a series of georeferenced events occurring differentially along a particular region, which determines spatial variations in density (in this study, the number of clusters with a reported occurrence of *P. oocarpa* per unit of surface area) (Salvati and Ferrara, 2015).

Thus, in order to map the spatial continuity of *P. oocarpa*, a density map was generated through Kernel density estimation (Fuenzalida *et al.*, 2013). This helps generate continuous surface densities in clusters with data of the species of interest using calculations of local vicinity carried out under the structure of a grid (a net of cells), where the density value at a given point (or a particular cell) is estimated in relation to the number of points (cells) where *P. oocarpa* is present. Specifically, the Kernel density estimation is a non-parametric technique based on several functions —quadratic function (Silverman, 1986), uniform function, Epanechnikov's function, normal distribution, triangular function, quartic function, etc. (Turlach, 1999)—, in which the near points have a greater influence on the determination of the density, while the distant points have a lower weighting. This is in accordance with the first law of geography, which states that everything is related to everything else, but those things that are nearer one other are more closely interrelated than things that are far apart (Tobler, 1970). Thus, the Kernel density estimator is defined using equation 1 (Amatulli *et al.*, 2007):

$$\hat{f}(x) = \frac{1}{nh^d}\sum_{i-1}^{n} K\left\{\frac{x-X_i}{h}\right\} \qquad (1)$$

Where:

n = Number of observation points

h = Bandwidth

K = Core module (kernel)

x = Coordinate vector representing the location where the function is estimated

X = Coordinate vectors representing each observation point

d = Number of dimensions in space

The spatial distribution of *P. oocarpa* was modeled based on the above expression; its maximum search radius parameter (bandwidth) was a distance of 9 051 m, according to Silverman's "golden rule" (1986).

Results validation

In order to compare between the different maps showing the distribution of *P. oocarpa* and the map resulting from the Kernel density model, a confusion matrix was determined for each of them; each matrix was based on the binary classification (YES = correct classification; NO = incorrect classification) of 221 systematically distributed points. For this purpose, the distribution of *P. oocarpa* determined by the distribution of likelihood resulting from the Kernel density estimation was assumed to be the actual distribution. The degree of agreement between the assigned classes was subsequently calculated by estimating the overall precision and the errors of omission and commission. However, since these statistics tend to overestimate the accuracy of the classification, the Kappa coefficient —which represents the percentage in which a given classification is better than the one resulting from the application of a random classifier— was calculated, using the following expression (Congalton, 1991):

$$\widehat{K} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r}(x_{i+}\, x_{+i})}{x^2 - \sum_{i=1}^{r}(x_{i+}\, x_{+i})} \qquad (2)$$

Where:

r = Number of rows in the matrix

x_{ii} = Number of observations in the element of row $_i$ and column $_i$ (the largest diagonal of the matrix)

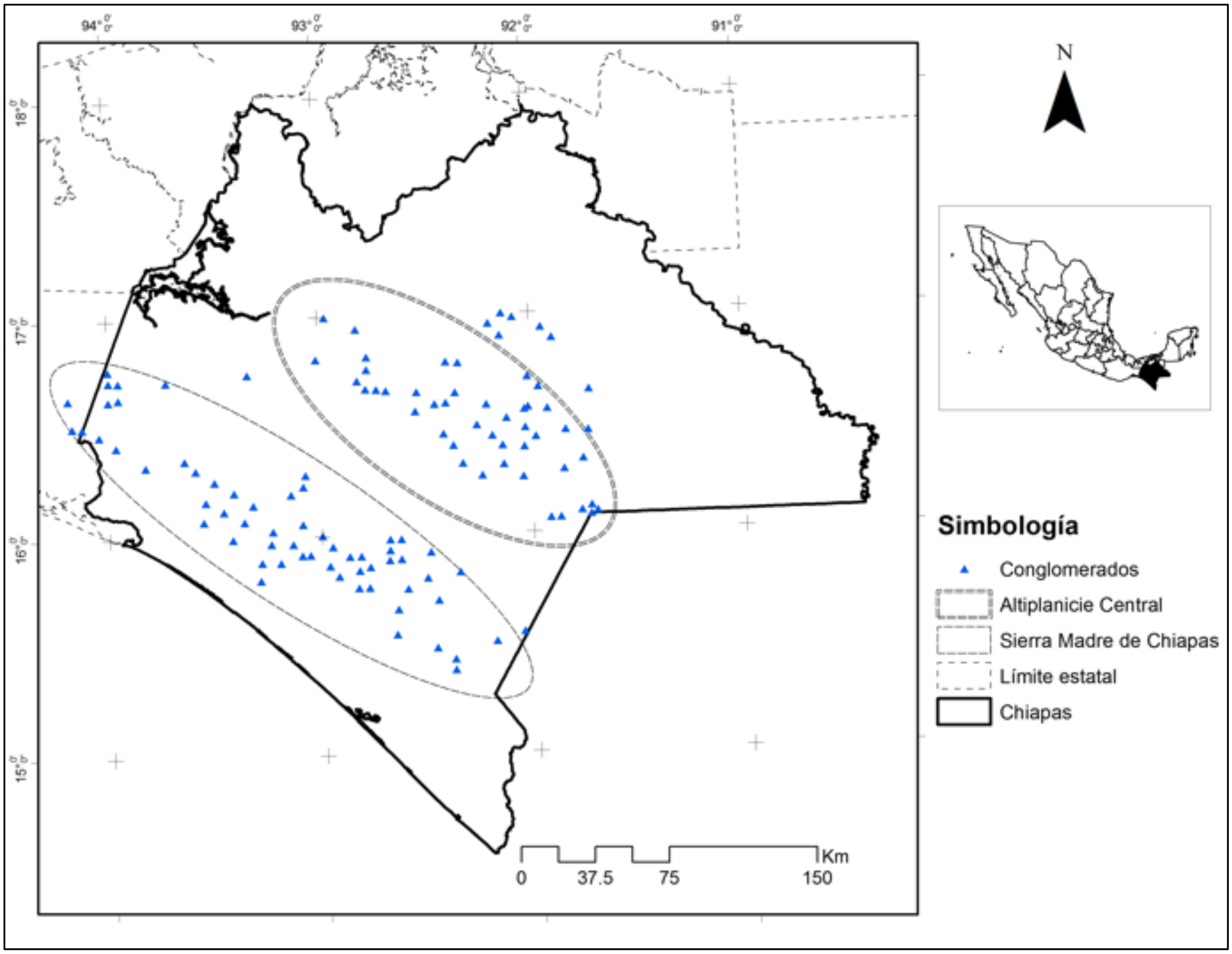
x_{i+} = Total number of observations in the row

x_{+i} = Total number of observations in the column

N = Total number of observations included in the matrix

Results and Discussion

Figure 4 illustrates the distribution of the 114 clusters of the INFyS where the presence of *P. oocarpa* in *Chiapas* was observed; these are distributed along the *Sierra Madre of Chiapas*, in the Central High Plateau and on the eastern mountains. The mensuration characteristics are summarized in Table 1.



Simbología = Symbology; *Conglomerados* = Clusters; *Límite estatal* = State limit; *Altitud* = Altitude.

Figure 4. INFyS clusters where *Pinus oocarpa* Schiede ex Schltdl. trees were identified in the state of *Chiapas* (Conafor, 2011).

Table 1. Average dasometric parameters of the INFyS clusters where the presence of *Pinus oocarpa* Schiede ex Schltdl. was detected.

Parameter	**Normal Diameter (cm)**	**Crown Diameter (m)**	**Total Height (m)**	**Stem Height (m)**	**Commercial Height (m)**
Average	31.05	3.41	13.4	7.17	9.94
Maximum	85	8.69	33.69	22.73	30.44
Minimum	9.25	0.65	4.99	1.49	1

The result of the definition of the spatial variation of the density of clusters with *P. oocarpa* made it possible to measure and delimit its distribution (Figure 5). Likewise, we should take into account that the number of clusters that, based on the probabilities, can occur within a km^2 circular area (Silverman, 1986), was determined through Kernel density estimation. Therefore, each cell contains the density value (cluster per km^2) that corresponds to the original distribution of the clusters of the INFyS. Although it is possible to consider the density of *P. oocarpa* trees in each cluster can be considered, the present study did not do so; therefore, the work was based exclusively on the condition of the presence of the species.

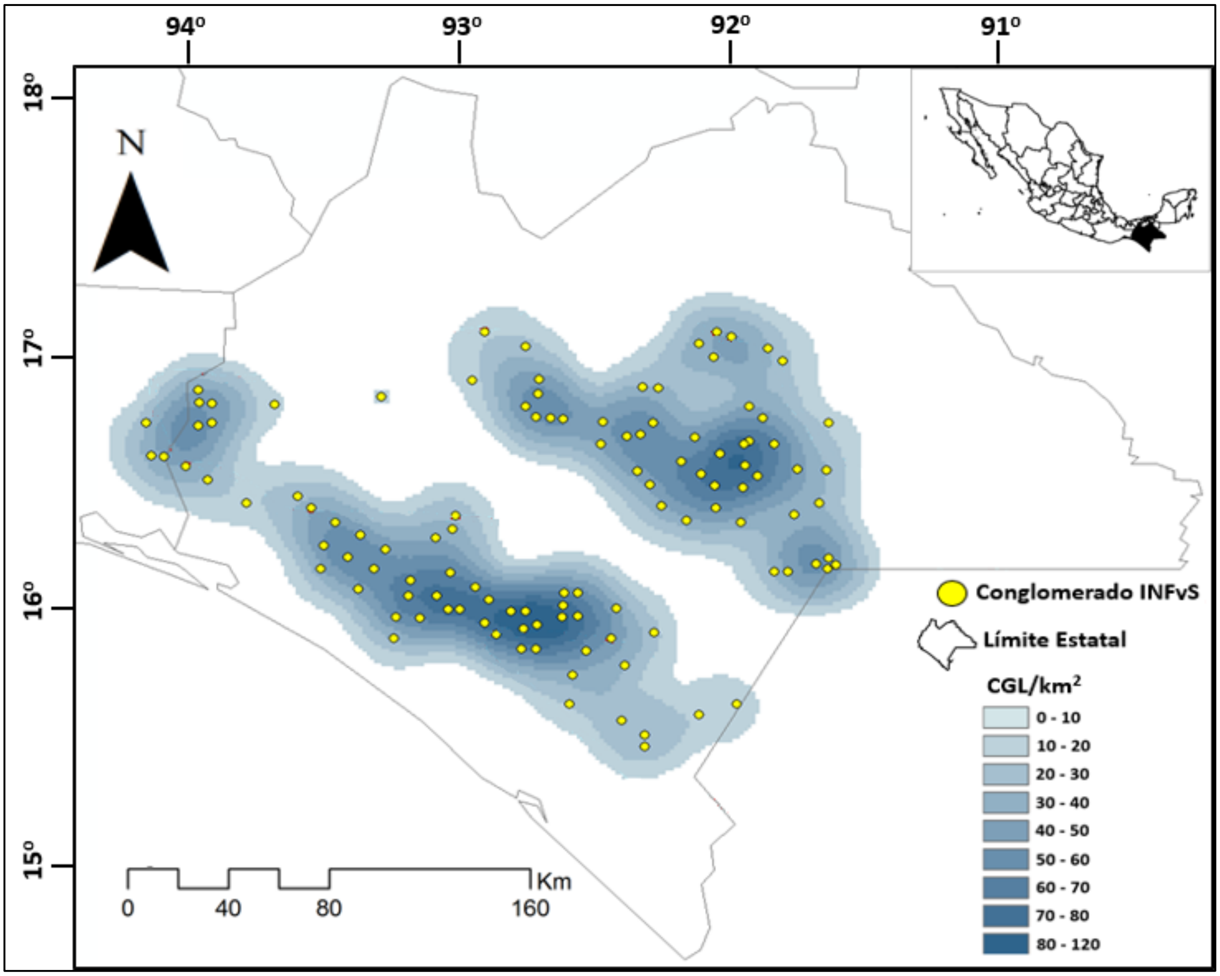


Figure 5. Estimation of the spatial distribution of *Pinus oocarpa* Schiede ex Schltdl., based on the *Kernel* density estimation.

The comparative analysis of the proposals concerning the geographical distribution of *P. oocarpa* takes into account the most recent cases (Figure 6). As for the qualitative analysis, it largely agrees with the results of the quantitative analysis shown in Table 2; in principle, the distribution proposed by the *Instituto Nacional de Investigaciones Forestales* (National Institute for Forest Research) (1974) had the greatest overall precision; it is followed by those of Farjon *et al.* (1997) and Eguiluz-Piedra (1985), with very similar overall precisions. On the other hand, the proposal by Perry (1991) evidences a geographical division between the distribution of the CHP and the SMC, which would imply a better approach to the actual distribution of *P. oocarpa*, compared to the distribution of Eguiluz-Piedra (1985).

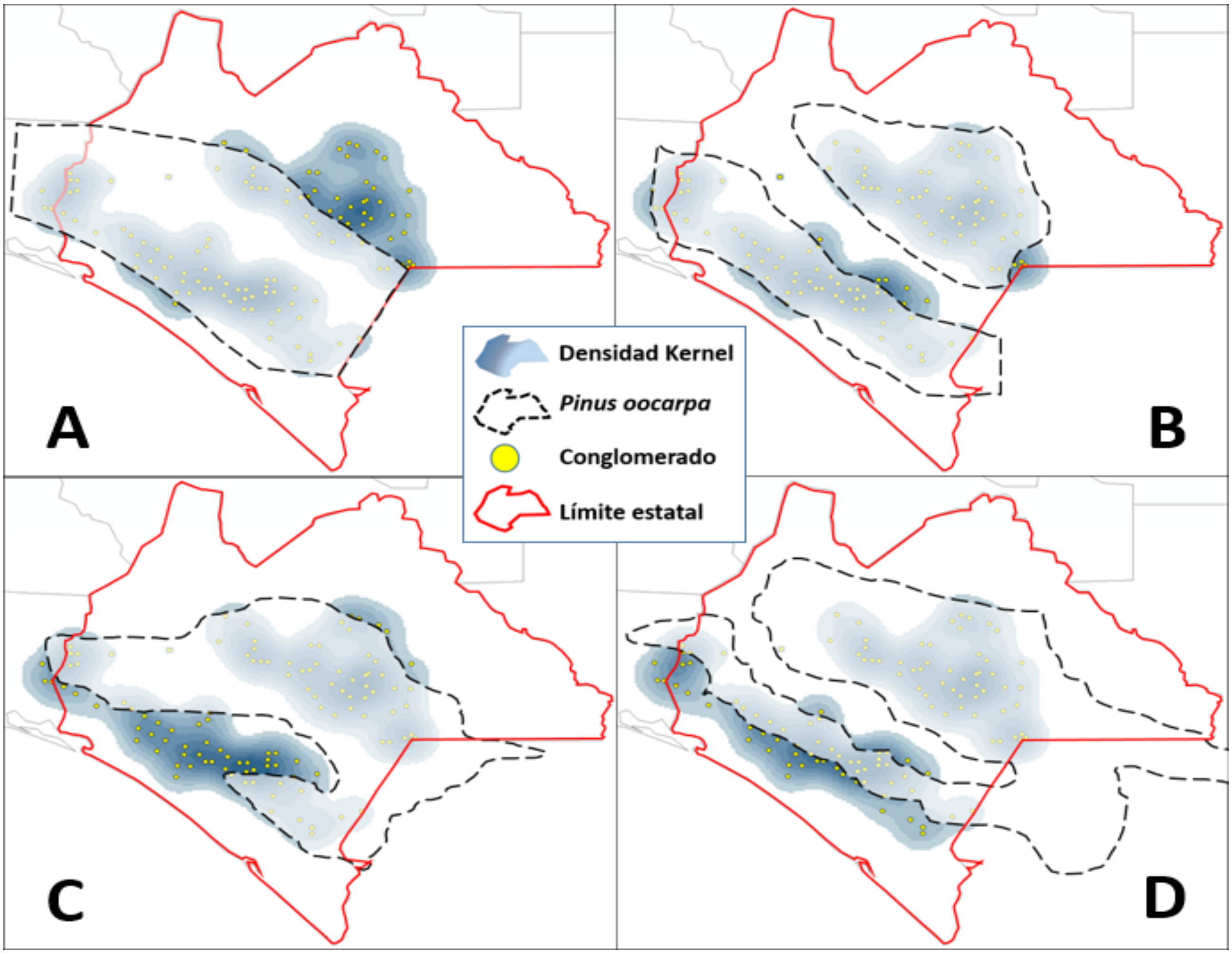


Figure 6. Graphic comparison of the distribution of *Pinus oocarpa* Schiede ex Schltdl. in the state of *Chiapas*: A. Eguiluz-Piedra, 1985; B. Instituto Nacional de Investigaciones Forestales, 1974; C. Perry, 1991; D. Farjon *et al.*, 1997.

Table 2. Statistics resulting from the analysis of the confusion matrix when comparing the various maps of the distribution of *Pinus oocarpa* Schiede ex Schltdl. in *Chiapas*.

Statistic	**1**	**2**	**3**	**4**
Overall precision	67.873	69.231	68.326	80.995
Kappa	35.695	38.354	36.837	62.065
Omission error	34.862	30.392	27.885	13.889
Commission error	31.731	34.259	35.345	22.500

1. Perry, 1991; 2. Eguiluz-Piedra, 1985; 3. Farjon *et al*., 1997; 4. Instituto Nacional de Investigaciones Forestales, 1974.

Nevertheless, the results of the corresponding confusion matrix showed that the proposal of Eguiluz-Piedra (1985) offers a greater overall precision. All of this is confirmed by the resulting values of the *Kappa* index.

According to the map of the location of *P. oocarpa*, this species is distributed mainly along the SMC and the CHP. The information contained in the clusters of the INFyS highlights the existence of trees with a normal diameter of almost 85 cm (at a height of 1.30 m), although these are rare. The average height of the trees was also observed to be low; i.e. most of the trees are at a youthful stage, or else, the species is located at places with low site quality, and as a result, the commercial height is also generally low.

The distribution determined through the Kernel density estimation has confirmed *P. oocarpa* to be located basically along the SMC and the CHP, as depicted in most of the illustrations of its geographical distribution. However, these clearly show a very approximate distribution, particularly in the maps that are previous to the 1990s (Mirov, 1955; Sánchez y Huguet, 1959; Eguiluz-Piedra, 1985), and a more accurate one in the versions of Farjon *et al*. (1997) and Perry (1991). Likewise, the distribution determined through the Kernel density estimation was found to agree with the exact location (sampling sites) of certain seed collection works (FAO, 1977) and studies on pests (Howell and Mathiasen, 2004).

However, certain sampling sites with *P. oocarpa* were located in unidentified areas at the INFyS, mainly to the southeast of the area between the SMC and the CHP, and at the center and north of the state, because these sites were sampled separately, without the purpose of defining the distribution of the species, and were not integrated into the density estimation.

From a qualitative perspective, and considering the actual distribution resulting from the Kernel density estimation, the geographical distribution of *P. oocarpa* cited by Eguiluz-Piedra (1985) agrees as to the area that covers the *Sierra Madre of Chiapas* (SMC), but differs in regard to a large part of the Central Plateau (CP). On the other hand, Perry's proposal (1991) covers the distribution of *P. oocarpa* in the region of the CHP, although not in the region of the SMC, particularly in its central area. The distribution of Farjon *et al.* (1997) comprises the whole length of the SMC, but the species is absent from certain areas of its width. Finally, the proposal of the National Institute for Research on Forestry (1974) is the one that most agrees with the distribution determined in the present study through Kernel density estimation; however, it exhibits a slight spatial overestimation.

Conclusions

The data of the INFyS make it possible to determine a spatial distribution of *P. oocarpa* that generally agrees with certain areas considered in previous proposals. However, we observe certain differences, as the previous studies basically tend to overestimate the distribution surface area due to: a) a somewhat inaccurate delimitation of the boundaries of the distribution areas, or b) a reduction of the distribution area of *P. oocarpa*, due to overexploitation or change of soil use. On the other hand, new areas with the presence of *P. oocarpa* are defined.

There are few works on the spatial distribution of *P. oocarpa*, which is specifically depicted in maps; however, the information is very approximate across distribution areas whose boundaries are not geographically outlined. For this reason, the sample intensity involved in the field work of the INFyS in the state of *Chiapas* allows ensuring a more accurate determination of the spatial distribution of *P. oocarpa*, which is conditioned only to the correct identification of the species in the sampling clusters.

The use of strategies such as the Kernel density estimation makes it possible to profit from the information that is intensively collected from the INFyS to generate information that can be used to support restoration and promotion activities related to *P. oocarpa* in the state of *Chiapas*.

The proposed methodology can be used in other regions where (national, state, regional, management, etc.) forest inventories are available, by restricting its definition of the distribution of the species of interest to the area covered by the sampling design.

Conflict of interests

The authors declare no conflict of interests.

Contribution by author

José Germán Flores Garnica: bibliographical research, modeling and analysis of the results and writing of the document; Oscar Reyes Cárdenas: bibliographical research, analysis of the results and writing of the document.

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