Article

Effect of the exclusion of a protected natural area in the composition and arboreal structure

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Abstract

The Izta-Popo National Park is a protected natural area (ANP) that was created with the purpose of maintaining the representativeness of the ecosystems. Currently, the situation of areas that were excluded from forest exploitation is not known. The objective was to evaluate the effect of the exclusion of an ANP on the composition and structure of the trees by means of dasometric characterization of a temperate forest in the central region of Mexico. Three square sites of 100 x 100 m (1 ha) were selected: two within the ANP (*Pinus hartwegii* “BPiHa” and *Pinus montezumae* “BPiMo”) and low forestry (*Abies religiosa* “BAbRe”), where the diameter was measured normal ($d_{1.30}$), total height (h), to calculate the basal area (G), total volume (vt), average diameter (d), average height (h), slenderness index (h/d), density (dn) The BPiMo has a density of 149 individuals, basal area (39.21 m^2 ha^{-1}), total volume (941.82 m^3 ha^{-1}), average diameters (55.34 cm) and average height (34.15 m). The BPiHa has a density of 133 individuals, basal area (23.27 m^2 ha^{-1}), total volume (328.47 m^3 ha^{-1}), average height (21.44 m) and average diameters (43.83 cm). The BAbRe, has a high density (315 trees ha^{-1}), basal area (32.37 m^2 ha^{-1}), total volume (468.58 m^3 ha^{-1}), average diameters (31.71 cm) and average height (24.22 m). The forests within the ANP (BPiMo and BPiHa) require timber harvesting, with the purpose of regenerating the forest mass. The BAbRe is under forest management and meets that condition.

Keywords: forest management, structural analysis, temperate forest.

Reception date: February 2018
Acceptance date: July 2018

Introduction

The Iztaccihuatl-Popocatepetl-Zoquiapan National Park, is located in the central region of Mexico. The Izta-Popo National Park is one of the oldest protected natural areas (ANP) in Mexico. It was created in 1935 to protect the mountains that make up the Sierra Nevada. This ANP was created with the purpose of maintaining the representativeness of ecosystems and their biodiversity, ensuring the provision of environmental services through their conservation and sustainable management.

Currently, it is not known what is the scenario of those areas that were excluded from forest management to belong to ANP, or if this type of management has been successful (not touching) with the assumption of a better conservation of biotic resources. A forest under management generates a wooded mass with better dasometric characteristics improving the services it presents and maintaining a constant flow of biotic resources unlike a forest that remains unused timber that tends to stabilize in the growth of the mass and remain stable. One of the most efficient ways to evaluate a tree mass, whatever it is, is through a dasometric characterization.

The dasometric characterization is a fundamental reference of the patterns and relationships within an ecological system, which involves regeneration, tree mortality and a variety of interactions between individuals, which in turn affects microclimatic conditions (Joao and Carvalho, 2011; Gadow *et al*., 2012) and is a way of estimating the condition of ecosystems at a given time and their evolution over time (Gadow *et al*., 1998; Vargas-Larreta *et al*., 2010; Petritan *et al*., 2012; Hui and Pommerening, 2014).

A correct characterization of ecosystems, serves to know the current state of existing vegetation that in turn will be used as a basis to make an adequate decision making for the management of forest resources, both in localities under use and in protected natural areas (Jiménez *et al*., 2001; Aguirre, 2003b; Wehenkel *et al*., 2011; Bannister and Donoso, 2013). For this purpose, structural indexes and dasometric variables are used, including diameter, height, basal area, etc, in order to achieve a better description (Aguirre *et al*., 2003a).

Worldwide there is enough literature to evaluate the structure of forest ecosystems (Liira *et al*., 2007; Joao and Carvalho, 2011; Brito-Rozas and Flores-Toro, 2014). In northern Mexico, there are studies that evaluate the structure of forest ecosystems, where they describe plant communities under forest exploitation (Aguirre *et al*., 2003a; Corral *et al*., 2005; Solis *et al*., 2006; Torres *et al*., 2006; García-De La Cruz *et al*., 2013; Hernández-Salas *et al*., 2013) and regenerated post-disturbance (Alanis-Rodríguez *et al*., 2008; Ávila-Flores *et al*., 2012); however, in the center of Mexico, there is scarce information on areas conserved under the protected natural area scheme. The present work focuses on comparing three forest areas, two located within a protected natural area (one of them with restricted access to the general public, another with access to the public) and the last, an area under forest use, said comparison it will be carried out by means of quantitative procedures that will allow to analyze with different precision the condition of the forest masses, in terms of their development and thus be able to define the bases to make an adequate decision making for the implementation of an adequate forest management of the studied areas, as an indispensable factor for the generation of tangible and intangible resources for the benefit of the most densely populated region of Mexico.

The proposed hypothesis was that the excluded forest will have a better state of conservation than the forests under management, since there is no deterioration of the resource because there is no interaction with human activities. For this reason, the objective of the present investigation was to evaluate the effect of the exclusion of a protected natural area in the composition and structure of the arboreal element by means of dasometric characterization of a temperate forest in the central region of Mexico, with the purpose of determine the current status of the forest resource.

Materials and methods

Study area. The study area is located in the eastern part of the Mexican Transversal Volcanic Axis (Figure 1). Two types of forest were selected in a protected natural area (*Pinus montezumae* Lamb. and *Pinus hartwegii* Lindl.) And a forest mass in a forest under management (*Abies religiosa* (H. B. K.) Schl. *et* Cham.)), Which are located between the following coordinates: 19° 00’ and 19° 28’ north latitude and 98° 35’ and 98° 46’ west longitude (Datum WGS 84).

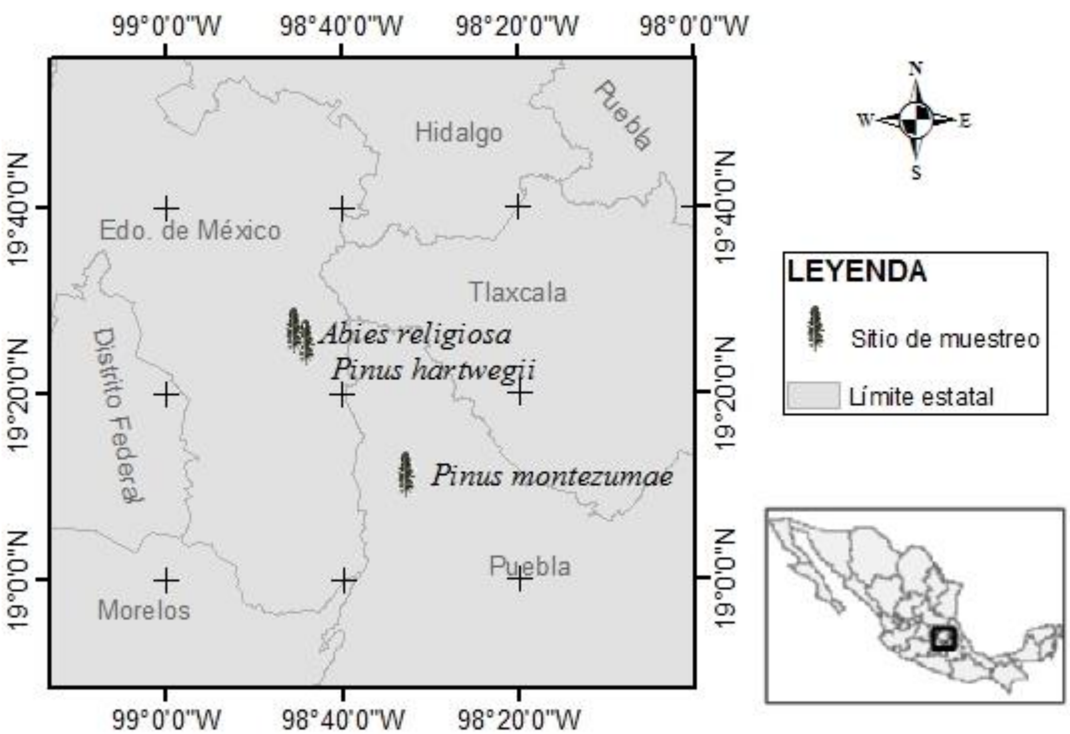

Figure 1. Location map of the study area.

To satisfy the proposed objective, three sampling plots with similar geographical characteristics were selected (Table 1). The mass of *Abies religiosa* has been harvested timber through the Mexican Method of Irregular Forest Management (MMOBI), after the ban was lifted in the State of Mexico (1969), that of *Pinus hartwegii* has not been used logically since 1948 it was determined as part of the Izta-Popo national park (DOF, 1948), and the mass of *Pinus montezumae* is a special case since 1963 it is located in what was the experimental forest field “San Juan Tetla” of the National Institute of Forestry, Agricultural and Livestock

Research (INIFAP) and only a few sanitation cuts were made, prior to that date (from 1948 to 1963) it was used by the Forest Exploitation Industrial Unit that supplied raw material to the San Rafael paper mill.

Table 1. Geographical characteristics and climatic data of the three sampling sites.

Vegetation	Forest of *Pinus montezumae* (BPiMo)	Forest of *Pinus hartwegii* (BPiHa)	Forest of *Abies religiosa* (BAbRe)
Coordinates (UTM)	547311 W 2121047 N	527518 W 2147240 N	525049 W 2149315 N
Altitude (masl)	3 300	3 600	3 000
Weather	C(w2)(w)(b')(I')g	C(w0)(w)b(I')g	C(w0)(w)b(I')g
*Annual average temperature (^{o}C)	12.5	15.8	15.8
*Precipitation annual average (mm)	815	650	650
**Type of soil	Humic andosol	Cambisol eutric	Cambisol eutric

*= Köppen climatic classification modified by García (1981); **= edaphology (INIFAP and CONABIO, 1995).

Data collection. Three plant communities of the temperate-cold forest (BPiMo, BPiHa and BAbRe) from eastern Mexico State and western Puebla were evaluated. The design consisted in establishing three square sites of 100 x 100 m (1 ha), which were subdivided into nine subsites of 33.33 x 33.33 m (1110 m^2). In the subsites, dendrometric information of the present tree species was taken, taking measurements of normal diameter ($d_{1.30}$), total height (h), of all the trees ≥10 cm of normal diameter.

Analysis of data. With the dendrometric information collected in the field, the basal area (G), total volume (vt), average diameter (d), average height (h), slenderness index (h/d), density (dn) were calculated for each site.

The basal area per unit area (1 ha) was defined as the sum of the cross sections of all the stems at the level of the normal diameter ($d_{1.30}$). For the values per hectare of the total volume, the summation of individual values was made, which were calculated with the allometric equations that are listed in Table 2.

Table 2. Equations used to calculate the total volume per tree.

Species	Formula	Author
Pinus montezumae	v=Anti ln(-11.285+ 1.1183∗ln(d^2∗h))	Acosta and Carrillo (2008)
Pinus hartwegii	v=Anti ln(-9.5377+1.9649∗ln d+0.89055∗ln h)	Rodríguez and Padilla (1976)
Abies religiosa	$v=0.00004432*d^{2.06319}*h^{0.86404}$	PROBOSQUE (1990)
Quercus laurina	$v=0.000066*d^{2.1380}*h^{0.6899}$	Pacheco (2011)
***Quercus rugosa*	$v=0.000066*d^{2.1380}*h^{0.6899}$	Pacheco (2011)
Alnus jorullensis	$v=0.000016737*d^2*h+0.000526d^2$	Quintana (1999)
Cupressus lindleyi	$v=0.00007204*d^{1.74008}*h^{1.04811}$	PROBOSQUE (1990)
Other latifoliadas	$v=0.00009001*d^{2.38434}*h^{0.16699}$	PROBOSQUE (1990)

v= is total volume; d= is the normal diameter; and h= is the height; **= was calculated with the same formula as Q. laurina, since they have similar morphological characteristics.

To calculate per hectare of the slenderness index, we obtained an average of the ratio (h/d), the density of a population (dn) was the number of individuals.

To detect if there are significant differences of the variables studied (basal area, total volume, average diameter, total height, slenderness index and density for the three types of forest masses studied, divided into nine sub-sites of sampling), an analysis of variance was applied. of one factor (Anova) If significant differences were found ($p < 0.05$), we proceeded with the multiple comparison of means using the Tukey test (Zar, 2010). The analyzes were performed with the statistical package SPSS® (ver. 19.0).

Results

Dasometric characterization. Within the study area, nine arboreal species were found, five of which are coniferous and four are broad-leaved. Of these species, three are of commercial timber importance: *Pinus hartwegii*, *P. montezumae* and *Abies religiosa*. The forest mass with the greatest number of individuals per hectare was that of *Abies religiosa* with 315, while for the dasometric variables the best mass was that of *Pinus montezumae*, with values of basal area of 39.21 m^2 ha^{-1} and a volume of 941.82 m^3 ha^{-1} in a population of 149 individuals per hectare. In contrast, the lowest values are for the *Pinus hartwegii* mass, where 133 individuals were recorded per hectare, with basal area values of 23.27 m^2 ha^{-1} and a volume of 328.47 m^3 ha^{-1} (Table 3).

Table 3. Densometric characteristics: basal area, total volume, average diameter, average height, slenderness index and density of the species of the three sampling areas.

Species	Average diameter (cm)	Average height (m)	Basal area (m^2 ha^{-1})	Total volume (m^3 ha^{-1})	Average slenderness index (h d^{-1})	Density (trees ha^{-1})
Pinus montezumae Lamb.	55.34	34.15	39.21	941.82	65	149
Pinus hartwegii Lindl	43.83	21.44	23.27	328.47	50	133
Abies religiosa (H. B. K.) Schl. Et Cham	31.71	24.22	32.37	468.58	84	315

With respect to the diameters of *Pinus montezumae*, these are distributed in bimodal form, presenting a greater number of individuals in the diametric categories of 55, 60 and 65 cm (42.95%) and fewer trees in the categories smaller than 40 cm (14.1%) (Figure 2A). This mass is made up of two strata in height, and most individuals are in categories of 35 and 40 m (67.11%) and a lower stratum with individuals with heights less than 10 m (Figure 2B). In the scatter plot (Figure 2C), it can be distinguished that there is a large number of trees in diameter classes of 40 to 80 cm and heights of 25 to 55 m and a smaller number is distributed between 15 and 35 cm in diameter. As a whole, this mass is conformed by an over-mature stand of two strata in height, with trees larger than 40 cm in diameter that could be susceptible to logging.

The mass of *Pinus hartwegii* has a bimodal distribution with a greater number of individuals in the diametric categories of 25 to 75 cm (Figure 2D), having a greater frequency in categories 45, 50, 55 and 60 cm (53.39%). For the distribution in height it is found in all categories with a greater number of trees in the categories of 25 and 30 m (65.41%) (Figure 2D). In the scatter plot (Figure

2F), it can be distinguished that there is a large number of mature trees in diameter classes of 45 to 55 cm and heights of 20 to 30 m. There is also a group of young individuals less than 15 cm in diameter and 10 m in height (Figure 2F).

This mass is formed by two strata in height and dominated by individuals of 25 m in height in the upper stratum and a lower stratum with trees in the category of 5 m in height. In Figure 2D, a diameter distribution is observed with presence in the categories of 10 to 75 cm (except in the 20 cm category). In the missing category (20 cm) is reflected in a lower frequency of individuals in the height category of 10 m. This mass is formed by a mature stand of two strata in height, with trees larger than 40 cm in diameter that may be susceptible to logging.

For the forest of *Abies religiosa* the diameters have a Poisson distribution with an asymmetry on the left, with a greater presence in the category of 15, 20 and 25 cm (41.57%) (Figure 2G). This mass is made up of two strata in height, and individuals are found more frequently in the category of 15 m (31.43%) and to a lesser extent in the category 35 m (21.27%) (Figure 2H). In the scatter plot (Figure 2I), it can be distinguished that there is a distribution of trees in all diameter classes up to 80 cm and heights of 45 m, of a uniform ascending shape and an isolated individual of greater diameter in the category of 100 cm and dominated by individuals with heights of 30-35 m in height and the second stratum with 15 m trees and few individuals greater than 40 cm in diameter that may be susceptible to logging.

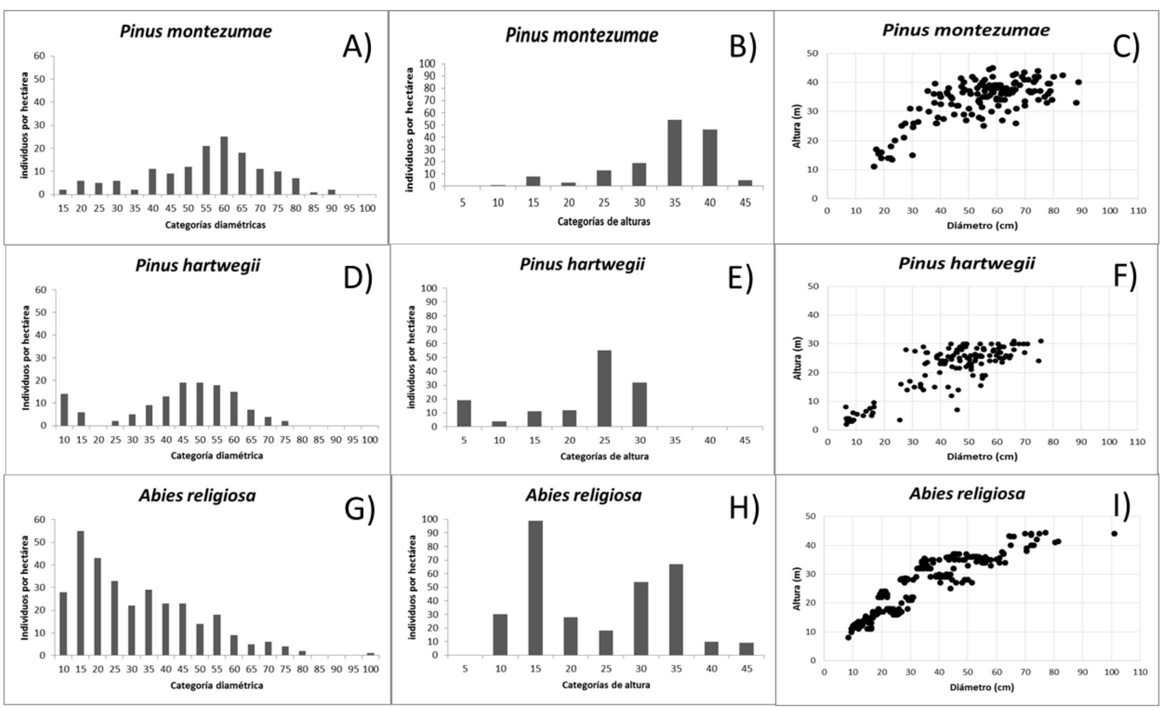

Figure 2. Distribution of individuals of the species by: A) diametric categories; B) height categories; C) dispersion diagram (height-diameter) of *Pinus montezumae*; D) diametric categories; E) height categories; F) dispersion diagram (height-diameter) of *Pinus hartwegii*; G) diameter category; H) height category; and I) scatter diagram (height-diameter) of *Abies religiosa*.

Comparison between three forest stands. The average diameter shows significant differences between the three areas ($p < 0.05$). The forest of *Pinus montezumae* has the highest value of 55.34 ±2.2 cm), followed by the forest of *Pinus hartwegii* (43.83 ±3.2 cm) and the smaller, the forest of *Abies religiosa* (31.71 ±0.9 cm) (Figure 3A).

The average height shows significant differences between the three areas ($p < 0.05$). The forest of *Pinus montezumae* has the highest value of basal area (34.15 ±2.1 m) and the forest of *Abies religiosa* (24.22 ±0.9 m) and the lowest, the forest of *Pinus hartwegii* (21.44 ±2 m) (Figure 3B).

The basal area presents significant differences between the three areas ($p < 0.05$). The forest of *Pinus montezumae* has the highest value of basal area (41.61 ±3.8 m^2 ha^{-1}) and the forest of *Abies religiosa* (34 ± 1.63 m^2 ha^{-1}) and the lowest, the forest of *Pinus hartwegii* (23.27 ±4.7 m^2 ha^{-1}) are similar to the other two forests (Figure 3C).

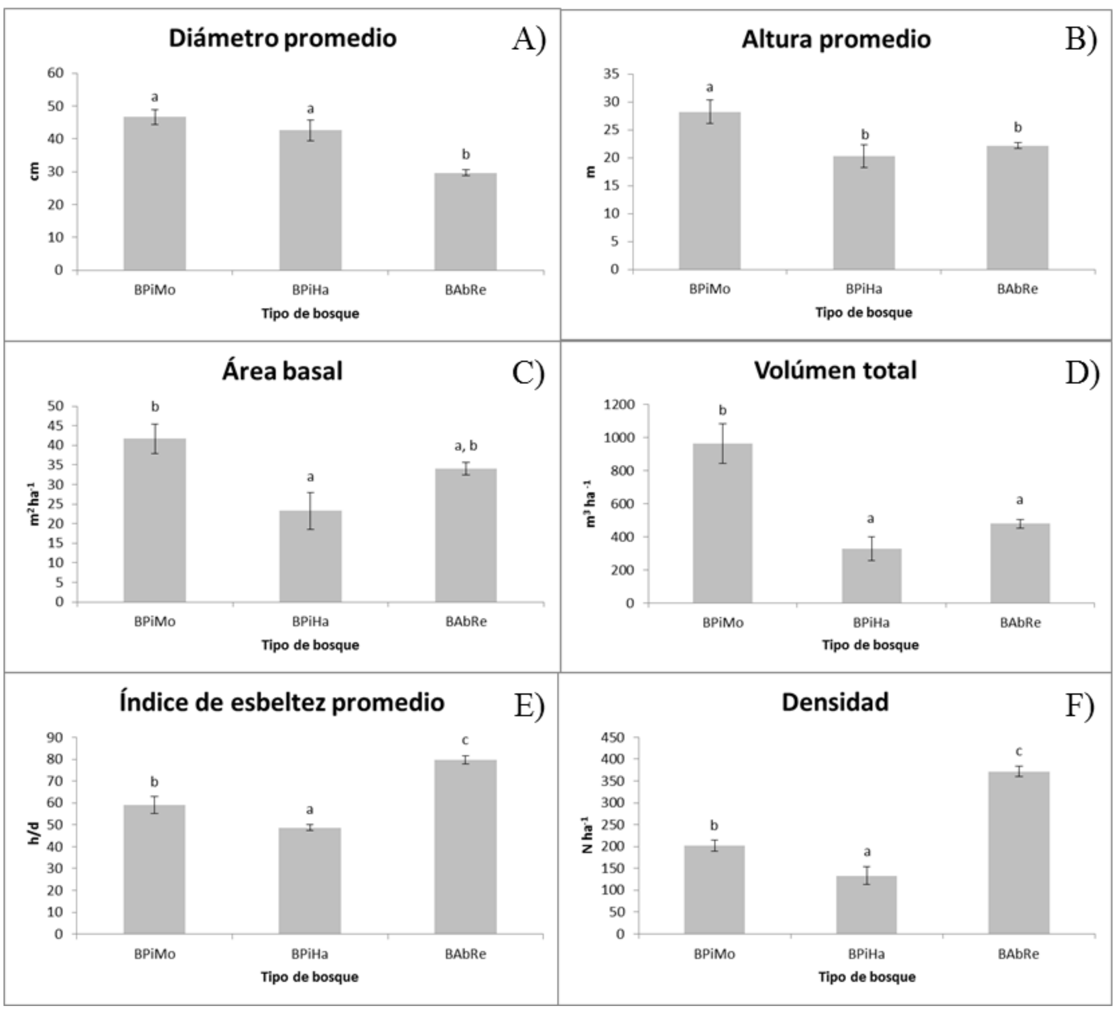

Figure 3. Means and standard error of A) average diameter (cm); B) average height (m); C) basal area (m^2 ha^{-1}); D) total volume (m^3 ha^{-1}); E) slenderness index (h d^{-1}); and F) density (trees (N) ha^{-1}). BPiMo= forest of *Pinus montezumae*; BPiHa= forest of *Pinus hartwegii*; BAbRe= forest of *Abies religiosa*. Means followed by different letters (a, b, c) indicate significant differences for $p < 0.05$.

The total volume also presents a significant difference between sampling plots ($p< 0.05$). The Forest of *Pinus montezumae* was the one that presented the highest level of total volume (962.67 ±119. 38 m^3 ha^{-1}) being different from the other two forests. The forests of *Abies religiosa* (478.91 ±27.41 m^3 ha^{-1}) and the forest of *Pinus hartwegii* (328.47 ±72.75 m^3 ha^{-1}) do not present significant differences (Figure 3D).

With respect to the slenderness index, the three forest types differ ($p< 0.05$). The forest of *Abies religiosa* has the highest slenderness indexes (68.5 ±1.86), followed by the forest of *Pinus montezumae* (59 ±3.91), and with a lower index the forest of *Pinus hartwegii* (50 ±1.34) (Figure 3E).

Finally, density also has a significant difference between forest types ($p< 0.05$). The highest density is the forest of *Abies religiosa* (369 ±12.64 trees ha^{-1}), followed by the forest of *Pinus montezumae* (202 ±12.56 trees ha^{-1}), and finally the forest of *Pinus hartwegii* (133 ±20.11 trees ha^{-1}) (Figure 3F).

Discussion

The mass of *Pinus montezumae* has a density of 149 individuals and has high values in basal area (39.21 m^2 ha^{-1}), and total volume (941.82 m^3 ha^{-1}); the above, is explained by the average diameters of 55.34 cm and average height of 34.15 m, which reflects individuals with low slenderness index (65) being robust trees. These values are the result of not being used in more than 50 years.

In the forest mass *Pinus hartwegii* has a density of 133 individuals and has low values in basal area (23.27 m^2 ha^{-1}) and total volume (328.47 m^3 ha^{-1}), these values are the result of individuals with index values of slenderness (50), which reflects low average trees of 21.44 m and average diameters of 43.83 cm. The above is explained by the altitude (3 600 masl) of the mass in the study area, which is why they are subject to a greater risk of demolition or rupture of the stem by wind.

Unlike the BAbRe masses, it has a high density of *Abies religiosa* (315 N ha^{-1}), which is a dominant species and has high values in basal area (32.37 m^2 ha^{-1}) and total volume (468.58 m^3 ha^{-1}); this is explained by the average diameters of 31.71 cm and average height of 24.22 m, which reflects individuals with high values of the slenderness index (84) resulting from its high density, this phenomenon is mainly due to the *Abies religiosa* is tolerant of shade.

The mass under forest management (BAbRe) have greater density in small diameter categories maintaining the dynamics of the forest, since new individuals are generated for the subsequent diameter categories, unlike the mature or over mature forests (BPiHa and BPiMo, respectively) that have greater representativeness in large diameter categories having a greater number of over-mature trees, which are susceptible to pests and diseases.

The mass of BPiMo presented high values of basal area (41.61 m^2 ha^{-1}), total volume (962.67 m^3 ha^{-1}), density (202 trees ha^{-1}) and slenderness index (65). These values are the result of conservation management (not wood extraction), since it is within the area of the “San Juan Tetla” Experimental Field of the INIFAP, which is totally protected from clandestinity. In other studies, such as those carried out by Zepeda and Acosta (2000), in a similar area, within the same experimental field, but in an area with access to the inhabitants of the region, the results show lower values, which were 25.12 m^2 ha^{-1} and 28.76 m^2 ha^{-1} (basal area), 341.93 m^3 ha^{-1} and 469.6 m^3 ha^{-1} (total volume) and 182 trees ha^{-1} and 168 trees ha^{-1} (density). With respect to the slenderness index (65), they are high values compared with studies of areas under management such as those reported by Corral-Rivas *et al*. (2005) that were 44 and 57 and those of 48 (Aguirre *et al*., 2003a), mainly due to cutting of trees with a larger diameter, leaving small diameters with good heights that are expected to increase in diameter during the cycle short.

For the mass of BPiHa registered the lowest indicators in all the characteristics studied. Since it is a mass that is in the Izta-Popo National Park area, but they are areas with little security and are clandestinely targeted by the inhabitants of the region. In this study, lower values of basal area (23.29 m^2 ha^{-1}), total volume (328.47 m^3 ha^{-1}), density (133 trees ha^{-1}) and slenderness index (50) were found, to those found in low forests management as reported by García (2000) that were 25.75 m^2 ha^{-1} and those reported by Aguirre *et al*. (2003a) 35.9 - 48.2 m^2 ha^{-1}, with a value of slenderness index ranging from 43 to 64 for different stands. For an area with similar climatic conditions, but in areas under forest management (MMOBI) PROBOSQUE (2010) reports a basal area of 35 m^2 ha^{-1} and a volume 965 m^3 ha^{-1} total for the pine group 2 (group generated by PROBOSQUE with *Pinus leiophylla*, *P*. *hartwegii* and *P*. *rudis*) the municipality of Texcoco.

The mass of BAbRe was the one that presented the highest values in the slenderness and density index. These values are the result of the forest management carried out in this area (MMOBI), which facilitates natural regeneration by maintaining a high number of individuals of smaller diameter categories. The values found in this study for BAbRe basal area (34 m^2 ha^{-1}), total volume (468.58 m^3 ha^{-1}), slenderness index (84) and density (369 trees ha^{-1}) were lower than those reported authors for forests under management such as those made by PROBOSQUE (2010) for basal area (50 m^2 ha^{-1}) and similar in volume (417 m^3 ha^{-1}) average values recorded in similar management conditions for the municipality of Texcoco. With respect to the values reported by Aguirre *et al*. (2003a) of slenderness index are lower (55 and 60) for *Abies vejari*, than those registered in this study (84). The basal area values were also lower than those reported by Cuevas-Guzmán *et al*. (2011) (48.5 to 60.5 m^2 ha^{-1}) and densities that varied from 608 to 954 trees ha^{-1}. While the values of basal area were higher than those reported by Encina-Domínguez *et al*. (2008) (16.44 m^2 ha^{-1}) with a density of 439 trees ha^{-1} that were greater than those reported in this study.

The diversity and structure of the compared forests reveal that in stands with similar conditions there is a difference in composition and structure, which is an example of the ecological complexity that results in the exclusion of a forest area.

Conclusions

The results indicate that there is an effect of the exclusion of a protected natural area in the composition and structure of the arboreal element. For this reason, the hypothesis that areas excluded from forest management are in a better state of conservation is rejected.

The masses of BPiHa and BPiMo that are found within the ANP, present irregular forests (mature and overmature forests), with similar behavior, since in the BPiHa no type of management has been applied since 1948 since it is at a higher altitude at 3 600 meters above sea level and the BPiMo is inside the facilities of the Experimental Field "San Juan Tetla" of the INIFAP. On the other hand, the BAbRe mass that is outside the area of natural protected and presents forest management has a regular forest behavior, due to the use of the MMODI, favoring forests with young individuals.

The forests that are within the natural protected areas (BPiMo and BPiHa) require timber exploitation, with the purpose of regenerating the mass and having young individuals that can provide all the tangible and intangible services. Since having individuals of different structure would lead to a greater number of microclimates which would be reflected in larger microhabitats, which would facilitate the establishment of new wildlife. While the BAbRe, which is under forest management already meets that condition.

The dasometric characterization of this type of forest provides a detailed picture of the state of the forest stands, which supports actions for sustainable forest management. The variables estimated in the present investigation evaluate basic and sensitive attributes of plant communities at different natural and anthropogenic pressures.

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