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Dedicated to Prof. dr. sc. ZVONIMIR DEVIDÉ on the occasion of his 80th birthday

Research on diameter growth and increment of some Mexican pines

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Research on pine diameter growth and increment was carried out in different Mexican forests. Many sample plots were established in the pine stands of central, southern and northern parts of Mexico (State of Mexico, State of Michoacan and State of Chihuahua respectively). The following six pines and one fir, selected on the sample plots, were cut: *Pinus patula* Schlecht. et Cham., *Pinus Montezumae* Lamb., *Pinus Michoacana* Martinez, *Pinus leiophylla* Cham., *Pinus douglasiana* Martinez, *Pinus lawsoni* Roezl. and *Abies religiosa* (H.B.K.) Schlechtendal et Chamisso. Diameter growth and increment curve were constructed by means of a stem analysis. Data about diameter growth and increment indicate the relation between the diameter outside the bark and the diameter inside the bark. The diameter growth of the investigated pines was compared with the diameter growth of pines from Germany, Croatia, New Zealand and Mexico. In the pine forests of *Pinus durangensis* the breast height diameter increment was measured by Pressler's increment borer.

Key words: pine diameter, growth, diameter increment, stem analysis, Mexico.

Introduction

With a population of 100,349,766 (July 2000) and a land area of 1,923,040 km^2, Mexico has about 49 million hectares of forest, mainly in the states of Chihuahua, Durango and Michoacán (Fig. 1). The pine forests of the temperate and cool regions are very important since they provide the pulpwood for Mexico's paper mills. In Mexico there are 42 species, 22 varieties and 9 forms of pine (CEDILLO 1983). The growth of pines generally depends on the altitude, which ranges from 1,000 m (e.g. *Pinus Michoacana*) to 2,900 m (e.g. *Pinus lawsoni*). Many years ago (1966, 1967) I was engaged at Chapingo university (Universidad autonoma Chapingo, Mexico, previously ENA, Texcoco, Mexico) as a FAO forestry expert of the United Nations to lecture on forest management, growth and increment for regular and postgraduate students. This was a fine opportunity for forestry research in the field. I established some sample plots in different pine forests in order to make some measurements and observations of pine trees. Growth and increment were my first interest.

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Although I then completed my research on the diameter growth and increment of some pines, this is the first publication of the results.

Fig. 1. The investigated areas in Mexico

Materials and methods

The Mexican conifers investigated

One half of the 49 million hectares of Mexican forests consist of conifers. The ecological conditions in some parts of Mexico are ideal for conifers, especially for pines, the most important trees in the country. This was the reason for this research to focus on the pines, particularly on the following species, which grow at various altitudes:

Pinus patula Schlecht et Cham.	1,800–2,700 m
Pinus montesumae Lamb.	2,100–2,900 m
Pinus michoacana Martinez	1,000–1,700 m
Pinus leiophylla Schl. et Cham.	1,700–2,400 m
Pinus douglasiana Martinez	1,750–2,800 m
Pinus lawsoni Roezl.	1,600–2,700 m
Pinus engelmanni Carr.	2,300–2,550 m
Pinus durangensis Martinez	2,550–2,800 m

In order to have an objective element for the comparison, the research was extended to *Abies religiosa* (H.B.K.) Schlechtendal et Chamisso. All these species were described in detail by VASQUEZ (1962) and VIDAKOVIĆ (1991).

Sample plots

1. Sample plot Sitio Temporal Chapingo No. 16, Mexico, State of Mexico; Local name: La Venta, the research area for the growth and increment of *Pinus patula, Pinus montesumae* and *Abies religiosa*, all growing together on the same sample plot with the following characteristics:

Area:	0.50 ha,
Silvicultural characteristics:	artificial mixed stand of pine and fir.
Mean annual precipitation:	1,211 mm,
Altitude:	2,600 m,
Mean annual temperature:	11.1 °C,
Age:	35–40 years,
Number of trees per 1 ha:	*Pinus montesumae* (280), *Pinus patula* (12), *Pinus leiophylla* (2), *Abies religiosa* (170)
Total volume per 1 ha:	342 m^3.

2. Experimental forest of INIF Campo Experimental del Instituto de Investigaciones Forestales Barranca de Cupatitzio, Uruapan, State of Michoacán, Mexico, the research area of the growth and increment of *Pinus michoacana, Pinus leiophylla, Pinus douglasiana* and *Pinus lawsoni* (INIF 1982).

3. The pine forest of Chihuahua, State of Chihuahua, Management unit Serie Madera (local name El Baño); The stand of *Pinus engelmanii* and *Pinus durangensis*.

Mean altitude:	2,500 m
Mean annual temperature:	14 °C
Mean annual precipitation:	572 mm
Number of trees per 1 ha:	520
Basal area per 1 ha:	25 m^2
Medium breast height diameter:	25 cm
Age:	60 years

4. Permanent sample plot Sitio Permanente Chapingo No. 8, State of Chihuahua, Mexico. Management unit: Serie El Largo (Bosques de Chihuahua)

Local name:	Banco de Balastre en Mesa del Huracán
Silvicultural characteristics:	»Bosque virgen de pino« (virgin pine forest)
Date of measurement:	May 30 and 31, 1966
Altitude:	2,600 m

Exposition:	NE
Inclination:	10°
Mean annual precipitation:	728 mm
Mean annual temperature:	14 °C
Shape and area of sample plot:	100 m × 50 m = 0.50 ha
Species:	*Pinus durangensis*

Stem analysis

Mexican pines show a seasonal periodicity of growth, i.e. periods of accretion alternate with periods of rest. Therefore we can distinguish annual rings, i.e. the annual diameter increment.

Six Mexican pines and one Mexican fir were cut in order to obtain data for the calculation of their breast-height growth and increment. Cross-sections were taken from each felled tree as follows: the first at the stump (20 cm above ground); the second at breast height (1.30 m above ground), and others at equal distances from one another (1 m or 2 m apart). The stem analysis was done according to KLEPAC (1976). In the stem analysis I was assisted by my collaborator MAS (1978).

The relation between the inside diameter (d) and the outside diameter (D) (d : D = k) helps in calculating the percentage (p) of the total bark volume by means of Meyer's formula $p = (1-k^2) \cdot 100$.

Results

On the basis of the »seven stem analysis« I constructed diameter growth curves (Fig. 2, 3, 4 and 5) for different species. The growth of all tree species follows a course similar to an »S« curve. The increment curve corresponds to the growth curve. The point of the inflection of the »S« curve indicates the culmination of the current diameter increment.

The diameter increment of *Pinus* culminates earlier than that of *Abies*. This order of sequence in the culmination of the diameter increment is in harmony with the requirements for light of these two species. The basis of these findings clarifies why *Pinus* is a more suitable species for the production of small-sized assortments.

Diameter growth curves (Figs. 2, 3, 4, 5) indicate the breast-height diameters (BHD) at different ages presented in tables 1 and 4. The data on diameter increment are presented in Table 2.

The diameter curves show that after 30 years some Mexican dominant pines reached the following BHD: *Pinus patula* 38.5; *Pinus montesumae* 40.1, and *Pinus michoacana* 35.0 cm (Figs. 2, 3, 5).

In the natural, unmanaged and virgin forests of *Pinus durangensis* the mean annual increment at breast height is 0.4 cm.

On the basis of 1914 measurements of bark thickness with a Swedish bark gauge, we obtained data about the relation between the inside diameter (d) and the outside diameter (D) (Tab. 3). The percentage of total bark volume for Mexican pines (p) is more than 25%.

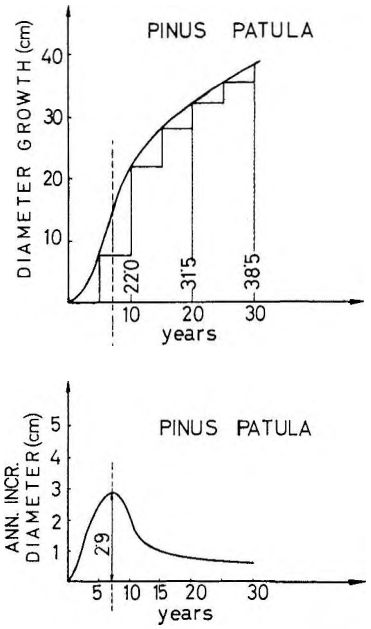

Fig. 2. Diameter growth and annual increment of the diameter in *Pinus patula*, in La Venta, Mexico (February 1967).

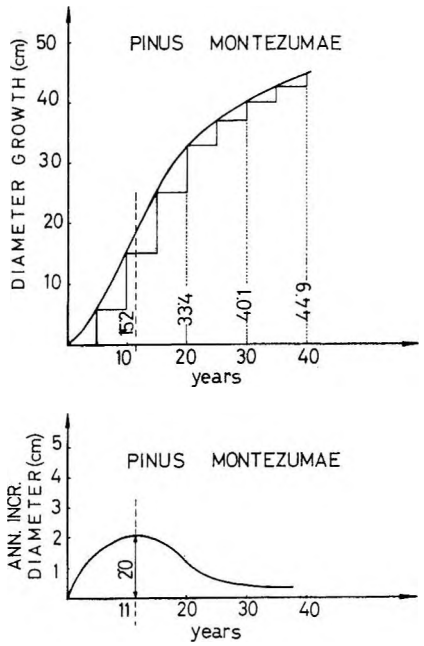

Fig. 3. Diameter growth and annual increment of the diameter in *Pinus montesumae*, in La Venta, Mexico (February 1967).

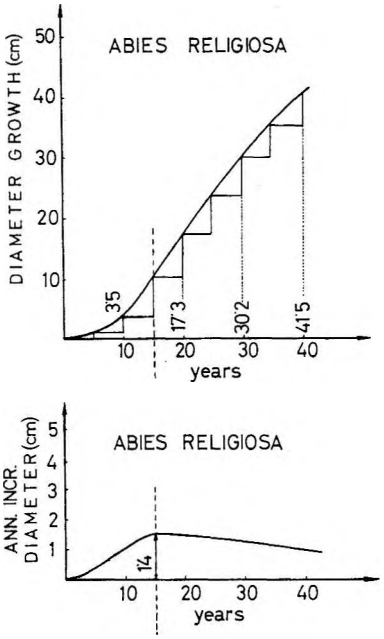

Fig. 4. Diameter growth and annual increment of the diameter in *Abies religiosa*, in La Venta, Mexico (February 1967).

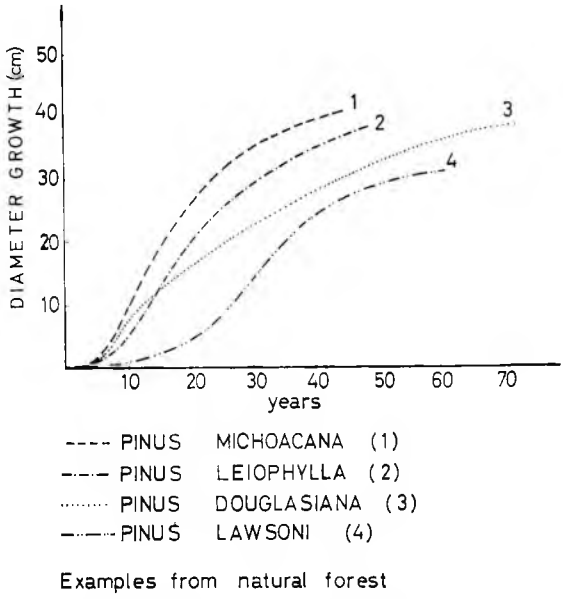

Fig. 5. Diameter growth of different pines in the natural forest in Campo Barranca de Cupatitzio, Uruapan, Michoacan, Mexico (September 11, 1967).

Tab. 1. Breast height diameters (BHD/cm) at different ages of *Pinus patula*, *Pinus montesumae* and *Abies religiosa* in Mexico (La Venta)

Species	Age	BHD (cm)
Pinus patula	10	22.0
	20	31.5
	30	38.5
	40	(42.5)
Pinus montesumae	10	15.2
	20	33.4
	30	40.1
	40	44.9
Abies religiosa	10	3.5
	20	17.3
	30	30.4
	40	41.5

Tab. 2. The diameter increment culmination of *Pinus patula, Pinus montesumae* and *Abies religiosa* in Mexico (La Venta)

Species	Approximate time of diameter increment culmination	Approximate annual diameter increment at culmination time
Pinus patula	age 7	2.9 cm
Pinus montesumae	age 11	2.0 cm

Tab. 3. The relationships between the breast height diameters (BHD, cm) with the bark (D) and the BHD without the bark (d) of different Mexican trees (State of Mexico)

Species	K = D:d	k = d:D
Pinus montesumae	1.1971	0.8387
Pinus ayacahite	1.1431	0.8776
Pinus hartwegii	1.1771	0.8522
Abies religiosa	1.280	0.8875

The bark thickness of the investigated species is relatively large, and thicker than in many European forests. The main reasons for this are most probably the special ecological conditions of these forests. On the other hand, they are relatively open. It is therefore evident that foreign data about the bark thickness are not applicable in Mexico. My collaborator

Luis Pimental was engaged in this research and published a study entitled »Investigaciones de la corteza para los especies forestales del Campo Experimental San Juan Tetla« (1966). He obtained the degree of Ingeniero Agronomo Especialista en Bosques on the basis of this study.

Tab. 4. Breast height diameters (cm) at different ages of various pines in Mexico, Germany, Croatia and New Zealand

Species/years	10	20	30	40	50	60	70	80	90	100
Pinus patula, Mexico	22.0	31.5	38.5	(42.4)						
Pinus montesumae, Mexico	15.2	33.4	40.1	44.9						
Pinus michoacana, Mexico	10.0	26.5	35.0	39.5						
Pinus leiophylla, Mexico	5.0	20.5	28.0	35.0	38.5					
Pinus douglasiana, Mexico	7.5	16.5	22.0	28.0	32.5	36.0	38.0			
Pinus lawsoni, Mexico	1.5	5.0	14.0	24.5	29.0	31.0				
Pinus silvestris, Germany			11.8	16.0	20.2	23.8	27.0	29.8	32.6	
Pinus halepensis, Croatia	0.5	2.4	8.4	13.2	16.8	19.6	21.8	23.5	25.0	26.3
Pinus radiata, New Zealand	12.2	27.5	38.5	45.7	51.7	56.0				
Pinus strobus, Croatia	5.4	18.3	26.0	30.4	33.0					
Pinus pseudostrobus, Mexico	6.5	17.6	26.0	32.2	37.1	41.1				

Discussion

In Table 4 I presented the diameter growth of six investigated Mexican pines and five pine species: *Pinus sylvestris* L. from Germany (SCHOBER 1975, Wiedemann moderate thinning, yield class I); *Pinus halepensis* Mill. from Dalmatia, Croatia (KLEPAC-KOVAČIĆ 1993), *Pinus strobus* L. (KLEPAC 1976) and *Pinus pseudostrobus* Lindl. (AGUIRRE 1989, best site class, moderate thinning) and *Pinus radiata* D. from Golden downs forest, New Zealand (SCOTT 1960). This table shows that the breast-height diameters of the Mexican pines *Pinus patula* and *Pinus montesumae* grow by about 40 cm during the period of 30 years, or by an average of 1.3 cm a year. Compared with the European pines *Pinus sylvestris* and *Pinus halepensis*, these pines are fast growing species (Tab. 4).

In the north Mexico pine forests of Chihuahua the annual diameter increment is smaller. In the management unit of Serie Madera (El Baño) I measured a mean annual diameter increment of 0.4 cm. The predominant species of this area were *Pinus engelmanni* and *Pinus durangensis*. In the same forest I carried out a heavy thinning with an intensity of 33%, in order to ameliorate and stimulate the diameter increment of standing trees.

I measured the same mean annual diameter increment of 0.4 cm in the virgin forest of *Pinus durangenis* in the management unit of Serie El Largo (Bosques de Chichuahua), locally named Banco de Balastre en Mesa del Huracan. Of excellent shape and wood quality, and with a mean breast-height annual ring of 0.2 cm, these pines are ideal for veneer production.

In recent years extensive research work focused on the stands of the Forest Faculty of the Universidad Autónoma de Nuevo Léon Sierra Madre Oriental, Nuevo Léon, Mexico has been performed (AGUIRRE et al. 1998, JIMÉNEZ et al. 1998, KRAMER et al. 1999). Stand structure research was carried out in a 2.18 ha uneven-aged mixed Pine-Juniper-Oak stand, situated in the training faculty forests. The favourable effect of thinning on the growth and stand structure (90% of *Pinus cooperi* and 10% of *Pinus leiophylla*) in a 12 hectare-large and 58 years old natural pine forest of Sierra Madre Occidental in northwest Mexico has been demonstrated (AGUIRRE et al. (1998) and KRAMER et al. (1998).

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