Article

Impact of debarkers upon the radial increment of Pinus teocote Schl. et Cham. and Pseudotsuga menziesii (Mirb.) Franco

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Abstract

Dendrochronological studies allow the dating of important events that influence tree growth. The objective of this study was to compare through dendrochronological techniques, the impact of bark beetles on the radial growth in *Pinus teocote* (*Pt*) and *Pseudotsuga menziesii* (*Pm*). Increment cores of 52 trees of *Pt* (26 healthy and 26 infested) and 72 of *Pm* (36 healthy and 36 infested) were analyzed at two sites located in the *Sierra Madre Oriental.* The analyzed data were: ring width and ring-width index, of the whole chronology, but also before and after bark beetles were registered. Through t-Student tests, the ring width of trees (healthy and infested) was compared before and after the attack of the insects. The accumulated radial increase in *Pt* was higher in infested trees (1.86 mm year^{-1}) than in healthy trees (1.30 mm year $^{-1}$); in *Pm*, healthy trees increased more (3.01 mm year^{-1}) than the infested ones (1.81 mm year^{-1}). In conclusion, each species responds differently to the attack of bark beetle insects, and this seems to be a way of preserving the species. Dendrochronology is a useful tool for evaluating forest productivity as it yields accurate data on age and annual increase of trees.

Key words: Ring-width, dendrochronology, *Dendroctonus* spp., Arteaga municipality, *Pinus teocote* Schiede. ex Schltdl. & Cham., *Pseudotsuga menziesii* (Mirb.) Franco.

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Introduction

Variation of concentrations of greenhouse gases (GHG) in the atmosphere is one of the main environmental problems that alter the climate and ecological system, which in turn causes fires, floods, forest pests and other problems, including Average surface temperature of the earth at 0.61 °C and is estimated to rise to 4 °C by the end of this century (IPCC, 2014). This is an influential factor in the physiology of forest insects, because they are cold blood (hemolymph) organisms, because they respond rapidly to their climatic environments (Menéndez, 2007). In addition to the above, changes in precipitation and frequency of extreme weather events are having a significant effect on the health status of the world's forests (FAO, 2007), by modifying the dynamics and biology of pests, their development, survival and reproduction (Swetnam *et al.,* 1985; Hawkins *et al*., 2013).

The organisms that most affect Mexican coniferous forests are bark insects of the *Dendroctonus* genus, where the most outstanding damage was observed in 1960 (Islas, 1980). Conafor (2015) reported that between 2004 and 2014, more than 30 365 ha were lost, which was attributed to 12 species of barkers, resulting in significant economic and ecological losses for the forest sector. Romero *et al*. (1997) refined the database of specimens of the Scolytidae (827) and Platypodidae (40) families; they live and reproduce in the internal cortex of the trees (FAO, 2007); they feed on the phloem and vascular cambium, thus causing the death of the host tree (Sánchez *et al.,* 2007).

The influence of these and other factors such as competition and climate are reflected in the ring width of tree growth (Swetnam *et al.,* 1985; Camarero and Martin, 2002; Hawkins *et al.,* 2013), which becomes apparent in a wider or smaller width (Schweingruber *et al.,* 1990). The ring sequences generated by the tree during its growth are studied by dendrochronology (Fritts, 1976), a science that dates the age of trees (Schweingruber *et al.,* 1990); this specialty has contributed to the solution of ecological, hydrological, climatic and archaeological problems

(Villanueva *et al.,* 2000; Villanueva *et al.,* 2009), but only a few studies include the impact of environmental change on forest communities

(Alvarado *et al.,* 1998).

Dendrochronological methods have been used in several forest species to carry out evaluations of the radial increase of the trees affected by different types of pests. In regard to debarkers, worth-mentioning are: Mast and Veblen (1994) on *Picea engelmannii* Parry ex Engelm. and *Abies lasiocarpa* (Hook. Nutt.); Zhang *et al.* (1999) on *Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco, *Abies lasiocarpa* and *Picea engelmannii* and *P. glauca* (Moench Voss); Rolland and Lemperiere (2004) on *Picea abies* (L.) H.Karst; Hawkins *et al.* (2013) on *Picea mariana* (Mill.) Britton, Sterns & Poggenb., *Pseudotsuga menziesii* var. *glauca* and *Picea glauca* x *P. engelmannii*. In defoliators: Swetnam and Lynch (1989) in mixed conifer forests (*Pseudotsuga menziesii* (Mirb.) Franco.), *Pinus ponderosa* Douglas ex. C.Lawson.*, Abies concolor* (Gordon) Lindl. ex Hildebr. and *Abies lasiocarpa*; Alfaro *et al.* (1985) on *Pseudotsuga menziesii;* Muzika and Liebhold (1999) on *Pinus rigida* Mill. and *Quercus* spp.; Camarero and Martín (2002) on *Abies alba* Mill. Grigaliūnas and Zolubas (2006) on *Ips* of *Picea abies* L. Karsten. Most of these studies show a significant reduction in the radial growth of host trees.

In Mexico, several of these species have been used for climatic reconstruction (Villanueva *et al.,* 2000, Villanueva *et al*., 2009; Cerano *et al*., 2011), but none to evaluate the effect of pests. Bark insects are one of the major threats to forests around the world when they appear after drastic changes in climate and ecosystem (Castello *et al.,* 1995), and woodland is more susceptible to damage from this kind; however, there is some uncertainty about how and how much these pests affect forest development or productivity.

Based on the above, the objective of the present study was to compare the impact of barking insects on radial growth by ring width in *Pseudotsuga menziesii* (Mirb.) Franco trees in Coahuila and *Pinus teocote* Schiede. ex Schltdl. & Cham. in Nuevo

León, Mexico, through dendrochronological techniques. It was hypothesized that healthy trees grow more radially than trees infested by debarking insects.

Materials and Methods

The study area

The study sites were located in *La Peñita* community, *Santiago* municipality *Nuevo León* and *Santa Rita ejido, Arteaga* municipality, *Coahuila*, both embedded in the *Sierra Madre Oriental*. The first one, in the 362409 and 2804175 UTM, coordinates, at 2 300 masl, a climate of the C type [C (W')] subhumid temperate, with a mean temperature between - 3 and 18 °C and annual precipitation between 600 and 900 mm (García, 1973). The second one is between the 353988 and 2791690 UTM coordinates, at 2 500 masl, a C (w_1) (i)w' climate of the subhumid temperate and subhumid with a temperature of -8 to 30 °C and an annual precipitation between 146 to 632 mm. The vegetation of each one is listed in Table 1.

Table 1. Average characteristic of the coniferous forest and the *Quercus* in the study area.

Species	**Number of trees per ha^{-1}**	**Height (m)**	**DBH (cm)**	**Basimetric Área (m^2 ha^{-1})**	**Proportion (%)**
		La Peñita, Santiago, Nuevo León			
Pinus teocote Schiede. ex Schltdl. & Cham.	28.6	12.1	21.5	4.4	47.0
Pseudotsuga menziesii (Mirb.) Franco	5.5	13.5	20.5	0.4	9.0
Quercus spp.	26.8	6.5	13.1	1.9	44.0
		Santa Rita, Arteaga, Coahuila			
Pinus rudis Endl.	54.3	15.1	29.5	12.1	21.3
Pinus reflexa (Engelm.) Engelm.	23.5	13.2	24.2	3.9	9.2
Pseudotsuga menziesii (Mirb.) Franco	19.6	15.6	25.8	4.7	7.7
Abies spp.	52.1	14.8	19.4	4.1	20.4
Quercus spp.	105.6	4.9	9.5	3.2	41.4

DBH = Diameter at breast height (cm); Proportion = Percentage that each species amounts.

Douglas fir (*Pseudotsuga menziesii*) is found in isolated populations of the *Sierra Madre Oriental*, *Sierra Madre Occidental*, *Eje Neovolcánico* and central part of the country (Domínguez *et al.*, 2004) and in small stands of *Oaxaca* state (Del Castillo *et al.*, 2004). *Pinus teocote* has a broad natural distribution in México and Guatemala and grows from 1 000 to 3 000 masl, in loam and clay loam soils. It is adapted to subhumid to humid climates, with annual precipitation from 1 000 to 1 500 mm (Dvorak and Donahue, 1993).

Field sampling

The collection of growth nuclei (cores) was carried out in *La Peñita, NL*, in June 2015, with 52 trees of *Pinus teocote* (Pt) (26 healthy and 26 infested) and in April 2016 in *Santa Rita, Coah*. 72 from *Pseudotsuga menziesii* (Pm) (36 healthy and 36 infested). From each tree two cores were extracted (one from north-south and one from east-west) using a Pressler drill (Haglof FOI0308) and size at 1.3 m height (Mast and Veblen, 1994; Camarero and Martín, 2002) The healthy trees (As) had a very strong vigor and no sawdust or galleries of any type of pest; the infested trees (Ai) had reddish needles and dead branches, bark with lumps of sawdust, galleries or exudation; both (As and Ai), should cover the same diameter categories and be free of competition (distance > 3 m to the nearest tree).

The mensuration characteristics were measured in plots of 50 x 50 m. The Ai were stripped a section of the shaft (30 x 20 cm) at the breast height to do a sampling of barking insects which were taken to the forest department of the UAAAN´s Laboratory for later identification.

Dendrocronological analysis

The cores were placed in a wooden base and were sandered to highlight the annual growth structures (Swetnam *et al*., 1985). The growth rings were counted and dated through standard dendrochronological techniques (Stokes y Smiley, 1968; Swetnam *et al*., 1985); they were individually measured through a Velmex with a

0.001 mm accuracy measuring system of sliding phase (Cerano *et al*., 2011) and each sample from the same tree and the same species was compared through crossdating (Stokes and Smiley, 1968; Camarero and Martín., 2002). The dating and the exact measurements of each ring was checked with the COFECHA program (Holmes, 1983; Grissino-Mayer, 2001).

With the ARTSAN program the biological (competition, suppression, release) and geometric (increase of the stump area with age) tendencies not related to climate and forest plagues were removed (Swetnam *et al*., 1985; Cook and Holmes, 1996). ARTSAN generated the standardized and residual ring width index (IAA) (Swetnam *et al*., 1985).

Analysis of growth and radial increase of *Pinus teocote* and *Pseudotsuga menziesii*

In order to corroborate that the average diameter and age between *As* and *Ai* were equal between species, a Student t test was applied through the Statistical Analysis System (SAS) software (SAS, 2014). To identify differences between *As* and *Ai*, the ring width (AA) and IAA data were divided into two groups: 1) total chronology and 2) last 10 years. In order to evaluate the radial increase of each species before and after the pest outbreak (2011), a cumulative AA was performed, five years before and five years later, in which a Student t test was applied to both groups data.

The percentage of reduction of the IAA was obtained by means of its average in the total chronology of *As* and *Ai* in both species. The ring width data (mm) were transformed to basal area (cm^2), from which the accumulated basal area (ABA) was derived; the Schumacher growth model was adjusted to these variables, with which the increase in basal area (IAB) in each species was determined. This model is expressed as follows:

$$Y = exp^{a+b/x}$$

Where:

Y = Basal area of each tree (cm^2)

x = Age of the tree (years)

exp = Exponential

a and *b* = Parameters of the model

Results and Discussion

In *La Peñita*, *Dendroctonus mexicanus* Hopkins, 1909 (55%), *D. frontalis* Zimmerman, 1868 (40%), *D. valens* LeConte, 1868 (4%) and *D. brevicomis* LeConte, 1876 (1%) were found. And, in *Santa Rita*, *D. adjuntus* Blandford, 1897 (72%), *D. brevicomis* (26.5%), *D. mexicanus* (0.8%), *D. valens* (0.5%) and *D. frontalis* (0.2%), all over *Pinus teocote (Coahuila*) and none over the forest species of the site of *Nuevo León* (Table 1). Only in *Pseudotsuga menziezii* (*Coahuila*) trees *D. pseudotsugae barragani* Furniss, 2010 (Salinas *et al*., 2010) were found. The intensity of the infestation by barking insects in each study site depends on its diversity, the forest species and their proportion in the forest.

Diameter and age of *Pinus teocote* and *Pseudotsuga menziesii*

The diameter and age in *As* and *Ai* of *P. teocote* was statistically the same (p = 0.6439 and p = 0.6922) (Table 2); the diameter was 39. 68 in *As* and 40.48 cm in *Ai,* with 84.81 and 82.91 years, respectively. In *As* and *Ai* of *Pseudotsuga menziesii*, the diameter was not statistically different (p = 0.1320), nor was age (p = 0.0867, Table 2); the diameter in *As* was 48.05 cm and 44.46 cm in *Ai,* with 79.64 and 86.28 years, respectively. Hawkins *et al*. (2013) have recommended that in order to assess this effect of increase by forest pests, the sample should be distributed over trees of the same categories; this study fulfills this premise.

Table 2. Student's t-test results in diameter and age of *Pinus teocote* Schiede. ex Schltdl. & Cham. in *Nuevo León* and *Pseudotsuga menziesii* Schiede. ex Schltdl. & Cham. in *Coahuila*, Mexico.

Species	Variable	Tree condition	n	Average	D.S	p-value
Pt (Coah)	DBH (cm)	Healthy	26	39.68	7.285	0.6439
		Infested	26	40.73	9.063	
Pm (NL)		Healthy	36	48.05	9.619	0.1320
		Infested	36	44.46	11.100	
Pt (Coah)	Age (years)	Healthy	26	84.81	21.498	0.6922
		Infested	26	82.91	18.903	
Pm (NL)		Healthy	36	79.64	13.076	0.0867
		Infested	36	86.28	18.072	

Pt = *Pinus teocote*; *Pm* = *Pseudotsuga menziesii*; DBH = Diameter at breast height; n = Number of trees; D.S. = Standard deviation.

Growth and increment of tree ring of *Pinus teocote* and *Pseudotsuga menziesii*

In *As* of *P. teocote* a chronology of 140 years (1875 - 2014) and of 124 years (1891 - 2014) in *Ai* were obtained. This study stands for one of the first intents to demonstrate the dendrochronological potential of *P. teocote*. In *Pseudotsuga menziesii* the chronology was 118 años (1898 - 2015) and 135 years (1881 - 2015) in *As* and *Ai,* respectively. In this same species and specialty, Zhang *et al.* (1999) in Canadá, revealed chronologies near 600 years; in New Mexico, United States of America, Swetnam and Lynch (1989) studied trees of only 180 years.

The dendroclimatic resarch studies made in Mexico over *Pseudotsuga menziesii* have reported from 203 (Arreola *et al*., 2010), 300 (Cerano *et al*., 2011) up to 554 years (Villanueva *et al*., 2009). The results here obtained prove that the forests of this species in this part of the country are in very contrasting developing stages, as differences from 68 to 436 years were recorded.

Table 3. Results of the *Student t* test of ring width in total chronology and the last 10 years in healthy and infested *Pinus teocote* Schiede. ex Schltdl. & Cham. and *Pseudotsuga menziesii* trees (Mirb.) Franco.

Species	Tree condition	AA (mm)	N	D.E.	p-value
Analysis with total chronology (G1)					
Pt (Coah.)	Healthy	1.73	140	0.87	0.0672
	Infested	1.92	124	0.838	
Pm (NL)	Healthy	2.99	118	1.536	0.1128
	Infested	2.71	135	1.245	
Analysis with the last 10 years (G2)					
Pt (Coah.)	Healthy	0.81	10	0.49	0.0591
	Infested	0.89	10	0.4	
Pm (NL)	Healthy	1.42	10	0.56	0.0001
	Infested	0.97	10	0.43	

Pt = *Pinus teocote*; *Pm* = *Pseudotsuga menziesii*; AA = Tree ring width (mm); N = Number of samples; D.E. = Standard deviation; G1 and G2 = Group one and two.

The Student t test (90 %) in the total chronology (G1) indicated that the ring width of *P. teocote* between As and *Ai* is statistically different (p = 0.0672) (Table 3, Figure 1A) with annual average growth of 1.73 mm in *As* and 1.92 mm in Ai. In the last ten years (G2), this species shows a different ring width between *As* and A*i* (p = 0.0591; Table 3) with AA of 0.81 and 0.89 mm. With the total chronology (G1), in *Pseudotsuga menziesii* there was no significant difference in AA between *As* and *Ai* (p = 0.1128) (Table 3, Figure 1B), resulting in an annual average growth of

2.99 in *As* and 2.71 mm in *Ai*; however, in the analysis of the last 10 years (G2), data show that *Pseudotsuga menziesii* diameter growth was higher in infested trees (p = 0.0001; Table 3). What is found here differs from what has been recognized for other species, as has been recorded with *Picea abies* affected samples (*Dendroctonus micans* Kugelann, 1794), on which Rolland and Lampériere (2004) calculated a reduction of 50 % in ring width.

In *Abies alba* attacked by defoliating insects (*Epinotia subsequana* Haworth, 1811), Camarero and Martín (2002) showed that in a three year period (1996 - 1998) the trees showed a reduction of 1.4 to 1.5 mm in comparison with healthy individuals, which responds to the depletion of carbohydrate reserves that are stored in the needles; this has also been reported by Muzika and Liebhold (1999) in other genera such as *Picea* and *Abies* in which the behavior is different, as pests do not affect growth in diameter (Grigaliūnas and Zolubas, 2006).

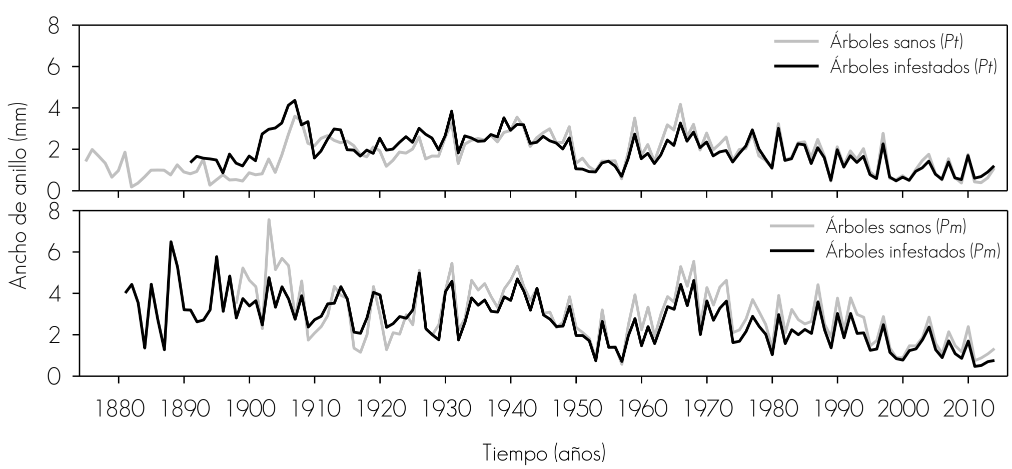

Figure 1. Ring width on total chronology of *Pinus teocote* Schiede. ex Schltdl. & Cham. (A) and *Pseudotsuga menziesii* (Mirb.) Franco (B) of two locations in Mexico.

Before the barking beetle outbreak, the infested *Pinus teocote* trees did not show significant differences in regard to the healthy ones (p = 0.1169). For *Pseudotsuga mensiezii,* the degree of damage had already an effect upon ring width (p =0.0143). After colonization, significant differences were found between healthy and unhealthy individuals of both species, even though it was the other way around, since ring width was greater both in attacked *Pinus teocote* trees as well as in those of the second species free of these insects (Table 4, Figure 2).

The species studied here responded differently in this variable to the infestation of barking beetles. In the fir, the reduction was 22.6 % before the insects and 39.8 % after them. It is possible that additional factors (not analyzed here) such as drought, among others, have contributed to this reaction. Some authors indicate that the spruce studied here is sensitive to the attack of forest pests, which is manifested in reductions of up to 50 %, especially if they are long-lived trees (> 100 years) (Alfaro *et al.,* 1985; Hawkins *et al*., 2013).

Table 4. Student t test results of the ring width increase before and after the pest outbreak in healthy and infested trees of *Pinus teocote* Schiede. ex Schltdl. & Cham. and *Pseudotsuga menziesii* (Mirb.) Franco.

Species	**Tree condition**	**IA-AA (mm year^{-1})**	**N**	**D.E.**	**p-value**
Before the barking beetle outbreak (2006 - 2010)					
Pt (Coah)	Healthy	2.63	5	1.56	0.1169
	Infested	2.58	5	1.55	
Pm (NL)	Healthy	4.63	5	2.7	0.0143
	Infested	3.58	5	2.01	
After the barking beetle outbreak (2011 - 2015)					
Pt (Coah)	Healthy	1.30	4	0.91	0.0017
	Infested	1.86	4	1.2	
Pm (NL)	Healthy	3.01	5	2.05	0.0181
	Infested	1.81	5	1.19	

Pt = *Pinus teocote*; *Pm* = *Pseudotsuga menziesii*; IA-AA = accumulated tree ring width (mm year^{-1}); N = number of samples; D.E. = standard deviation.

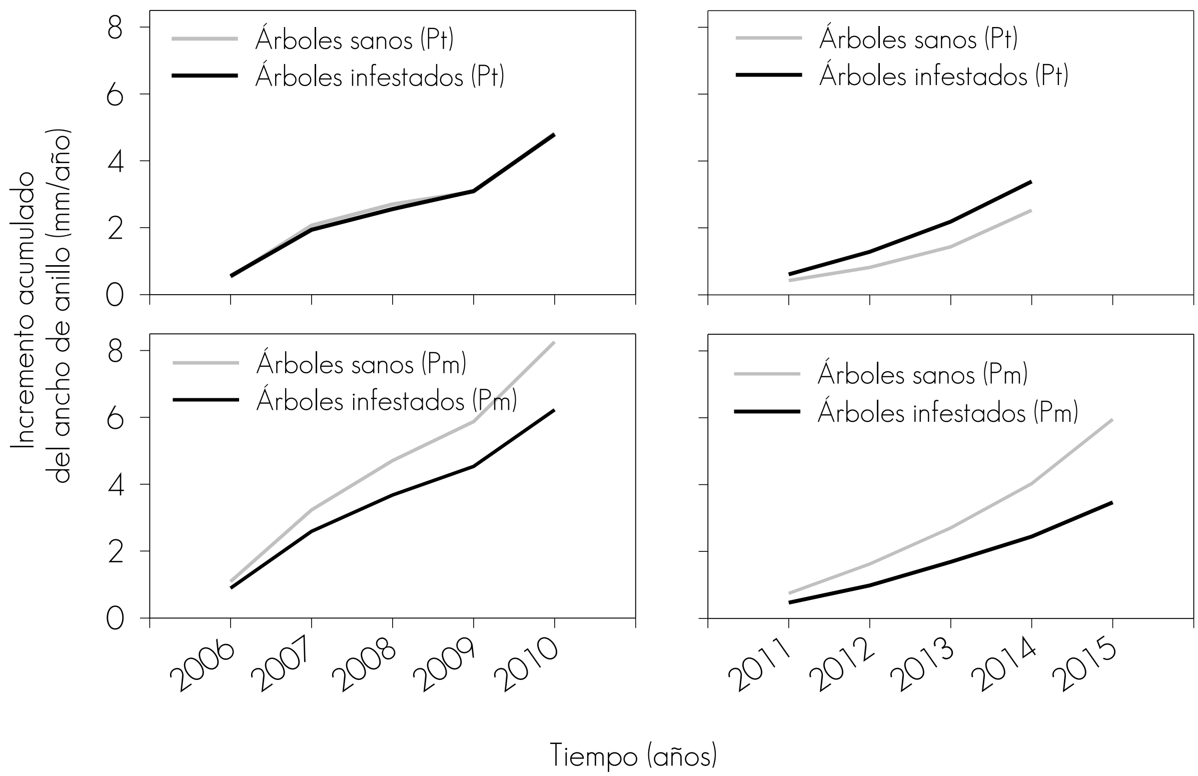

Figure 2. Ring width increment before (A - B) and after (C - D) the appearance of plagues over *Pinus teocote* Schiede. ex Schltdl. & Cham. (*Pt*) y *Pseudotsuga menziesii* (Mirb.) Franco (*Pm*).

***Pinus teocote* and *Pseudotsuga menziesii* ring width index**

The average IAA of *P. teocote* in total chronology (G1) and in the last ten years (G2) in As (0.98; 0.85) and in *Ai* (0.99; 0.87) do not show statistical differences (p = 0.8912; P = 0.9360) (Table 5), in *Pseudotsuga menziesii*, the IAA in the total chronology and in the last ten years also did not differ statistically (p = 0.4728; 0.7061) between As (0.96; 0.87) and *Ai* (0.99; 0.81) (Table 5).

In a Student t test performed with the data of the accumulated IAA increase after the outbreak, statistical differences (p = 0.0113; p = 0.0193) were found for *P. teocote* and *Pseudotsuga menziesii*, the first with *As* and *Ai* Of 1.75 and 1.49 and the second with 1.67 and 1.93 in *As* and *Ai*, respectively. Compared with the results of the ring width accumulated after the outbreak, these results indicate that there is an impact of the bark insects on the radial growth of the trees.

Table 5. Student's t test results of ring width index in the total chronology and in the last 10 years in healthy and infested *Pinus teocote* Schiede. ex Schltdl. & Cham. and *Pseudotsuga menziesii* (Mirb.) Franco trees.

Species	Tree condition	IA-AA (mm year^{-1})	N	D.E.	p-value
		Analysis with total chronology			
Pt (Coah)	Healthy	0.98	140	0.412	0.8912
	Infested	0.99	124	0.342	
Pm (NL)	Healthy	0.96	118	0.392	0.4728
	Infested	0.99	135	0.375	
		Analysis with the last 10 years			
Pt (Coah)	Healthy	0.85	10	0.4947	0.9360
	Infested	0.87	10	0.4009	
Pm (NL)	Healthy	0.87	10	0.3551	0.7061
	Infested	0.81	10	0.3453	

Pt = *Pinus teocote*; *Pm* = *Pseudotsuga menziesii*; IA-AA = accumulated tree ring width); N = number of samples; D.E. = standard deviation.

Figure 3A shows a reduction of IAA in *As* and *Ai* of *P. teocote* of up to 30 % in the 1916-1918, 1920-1925 and 1950-1953, 1955-1958 periods, during which a reduction of the IAA in *As* and *Ai* of *Pseuddotsuga. menziesii* up to 45 % (Figure 3C) occurred; the behavior up to 50 % was observed in 2011 in both species (Figures 3B and 3D). In precipitation reconstruction studies for the southeast of *Coahuila* and north of the country (Cerano *et al.,* 2011; Villanueva *et al.,* 2009), the following dry periods were obtained: 1890-1902, 1916-1933, 1951-1963, 1970-1985 and 1994 onwards, which coincides with the lapses of IAA reduction in *As* and *Ai* in the two taxa.

After the pest outbreak, in *P. teocote* the difference of the *Ai* reduction with respect to *As* was 9.3, 16.2, 11 and 5 % in the years 2011, 2012, and 2014, respectively (Figure 3B). In contrast, in *Pseudotsuga menziesii,* in which healthy trees recorded a lower reduction in IAA compared to the infested, with differences of 6.3, 11.6, 11.4, 15.7 and 24.2 in the years 2011, 2012, 2013, 2014 and 2015 respectively (Figure 3D), there is a positive response to the attack of barking insects for the pine and negative for the spruce.

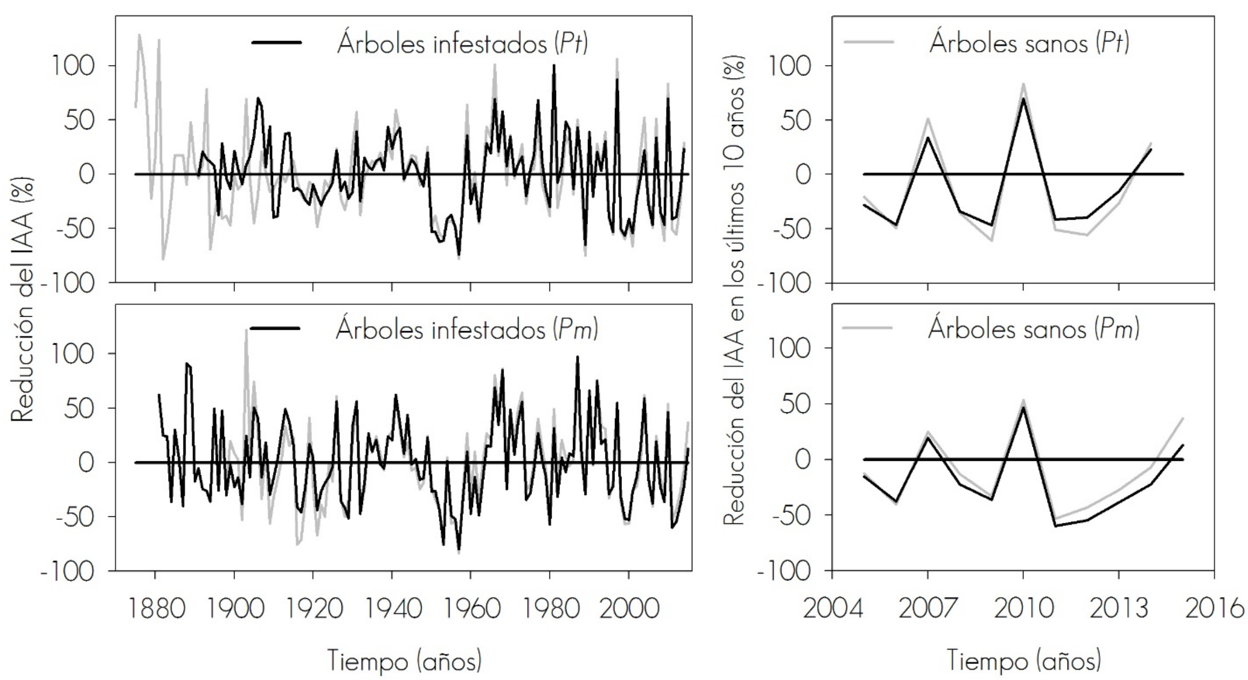

Figure 3. Percentage of reduction of the ring width index in the total chronology (A - B) and in the last ten years (C - D) in *Pinus teocote* Schiede. ex Schltdl. & Cham. (*Pt*) and *Pseudotsuga menziesii* (Mirb.) Franco (*Pm*) healthy and infested trees.

Basal area and increment of basal area of *Pinus teocote* and *Pseudotsuga menziesii*

The Schumacher growth model adjusted to the basal area of *As* and *Ai* individually resulted in high statistical significance (p <0.0001) in the two forest species (Table 6). The AB of the *Ai* of *Pseudotsuga menziesii* is the one that showed the best fit with R^2_{aj} = 0.8545; on the contrary, the *Ai* of *Pinus teocote* presented the lowest fit (R^2_{aj} = 0.7015). The analysis of the above shows that the greatest variation in AB is observed in the *Ai* of the pine, while the smallest was calculated in the *Ai* of *Pseudotsuga menziesii,* with CV = 44.4829. The results show important variations within each species, as in *P. teocote* the *As* have a smaller variation (VC = 50.7667), opposite to the spruce in which this occurred in *Ai* (Table 6).

Table 6. Statistic for the fit of the growth model of basal area in Schiede. ex Schltdl. & Cham. and *Pseudotsuga menziesii* (Mirb.) Franco.

Statistics	***Pinus teocote***		***Pseudotsuga menziesii***	
	Healthy	**Infested**	**Healthy**	**Infested**
a	5.8555	5.9821	6.8311	6.4586
b	-15.2036	-17.5183	-30.5521	-21.1762
a (E.E.)	0.0189	0.0283	0.0190	0.0142
b (E.E.)	0.7604	1.1761	0.9068	0.6676
R^2 aj.	0.8155	0.7015	0.8484	0.8545
C. V.	50.7667	69.8421	47.1034	44.4829
F Value	4 869.6	2 434.9	8 330.5	10 007.6

Pr > F	< 0.0001	<0 .0001	< 0.0001	< 0.0001
CME	11 918.9	25 696.6	33 041.1	24 655.3
Gl of the total	2 205	2 074	2 978	3 411

a and *b* = Regression coefficient of Schumacher's model; E.E.= Standard error of the regression coefficients; R^2_{aj} = Adjusted determination coefficient; C.V. = Variation coefficient; Pr > F = F probability; CME = Mean squared error; Gl = Degrees of freedom of the total of the model.

The average cumulative basal area according to Schumacher's growth model, in *P. teocote's As* was 215.1 cm^2 and 229.5 in *Ai*. The highest increase in AB was in the first 25 years *of age*, in *As* with 190.1 cm^2 and in *Ai* with 196.6 cm^2 (Figures 4A and 4B). In *Pseudotsuga menziesii*, in *As* an average of 385.9 cm^2 and of 352.9 cm^2 was recorded in *Ai*, and the highest increase in AB was at 40 years of age with 431.5 cm^2 in *As* and 375.8 cm^2 in ^{A}i (Figures 4C and 4D). The increase of AB in *Ai* of the latter species is lower compared to As; this is similar to the results of Rollan and Lamperiere (2004) in *Picea abies*, where this occurred in the first 35 years with 400 cm^2 in healthy trees and 350 cm^2 in trees affected by *Dendroctonus micans.*

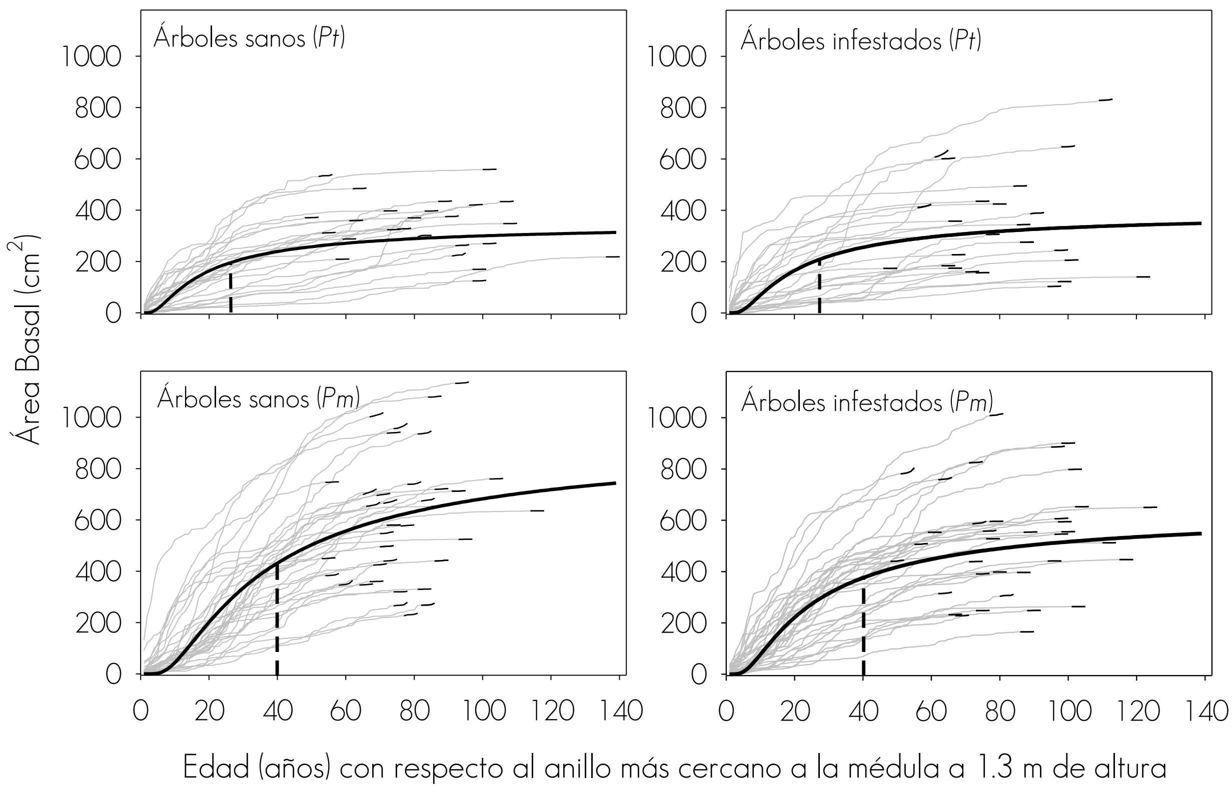

Figure 4. Basal area observed and estimated in *Pinus teocote* Schiede. ex Schltdl. & Cham (Pt) and *Pseudotsuga menziesii* (Mirb.) Franco (Pm) healthy (A-C) and infested (B-D) trees.

Figures 5A and 5B show the same pattern of increase in basal area in both species, but there are peaks below the average. In the pine, the *As* (14.8 cm^2 year^{-1}) and *Ai* (14.4 cm^2 year^{-1}) show these peaks in the 1952 - 1957, 1989, 1998 - 2002, 2006, 2008 - 2009, 2011 - 2012 periods, and although in the total chronology the average is similar, after the outbreaks of barking beetles (2011-2014), those figures vary more (9.5 cm^2 year^{-1}; 12.6 cm^2 year^{-1}) in *As* and *Ai.* In *Pseudotsuga menziesii* the peaks below the IAB average were at the same lapses in *As* and *Ai*, with values of 33.2 and 34.5 cm^2 year-^{1} respectively; after the outbreak, they became smaller, up to 26.2 and 15.9 cm^2 year^{-1}, the latter of which means a difference of 10.3 cm^2 year^{-1} between healthy and infested trees, thus affirming the negative impact on the radial increase of this forest species.

The IAB in the total chronology and after the outbreak on this latter species is rather low compared to the 54 cm^2 $year^{-1}$ recorded for dominant healthy trees of *Pseudotsuga menziesii* of the state of Chihuahua, where the age of the trees varies from 67 to 240 years (Castruita *et al.,* 2016), although dominant and codominant trees were selected for this study.

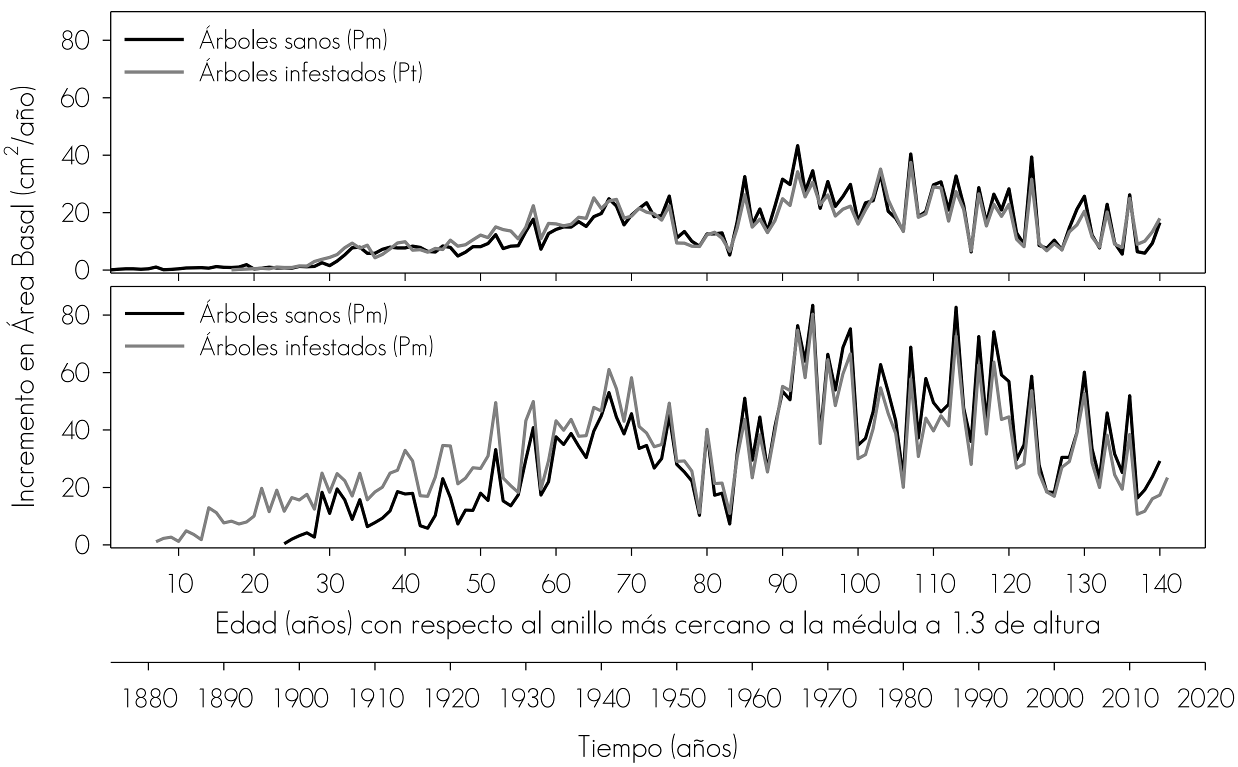

Figure 5. Increment of the basal area in regard to the age of the *Pinus teocote* Schiede. ex Schltdl. & Cham. (A) and *Pseudotsuga menziesii* (Mirb.) Franco. (B) healthy and infested trees.

Conclusions

The response to the attack of debarking insects of the studied forest species is different from each other; the accumulated radial increment (AA and IAA) in *Pinus teocote* after the barking beetles attack is greater in infested trees than in healthy trees, although it may be a strategy of the individual before dying, whereas in *Pseudotsuga menziesii* the opposite occurs.

Dendrochronology is a tool recommended for the calculation of the ring width index, since it removes the tendencies of age and competition, as well as internal and external factors of the species. The productivity of Mexico's forests is affected by bark insects, and depends on the pest, host species as well as on the stage of forest development.

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Conflict of interests

The authors declare no conflict of interests

Contribution by autor

Jesús Ángel López Sánchez: fieldwork, laboratory, materials, methods and statistical analysis; Jorge Méndez González: support in the preparation of the manuscript; Alejandro Zermeño González: support in the revision and writing of the manuscript; Julián Cerano Paredes: laboratory work in dendrochronological analysis; Mario Alberto García Aranda: field work and support in the analysis of results.