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Research article

Impacto de *Ips confusus* Wood & Bright, 1992 en el incremento radial de *Pinus cembroides* Zucc.

The impact the *Ips confusus* Wood & Bright, 1992 on the radial growth of *Pinus cembroides* Zucc.

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Abstract

Forest pests are one of the primary disturbance factors in the temperate forests of Mexico. *Ips confusus* attacks *Pinus cembroides* trees, especially after intense droughts. The aim of this study was to assess the impact of *I. confusus* on the annual radial growth of a *P. cembroides* forest in the *Carichí* municipality, state of *Chihuahua,* México. Additionally, the influence of climatic variables was determined. Increment cores were extracted from both attacked (AA) and non-attacked *P. cembroides* trees (ANA). A total of 53 increment cores were dated, spanning from 1776 to 2012 (AA=24 and ANA=29). Starting from 1998, differential basal area growth was observed between AA and ANA. By the time of tree mortality in 2012, a difference of over 100 % was recorded (AA=8.03±1.53 cm^2 $year^{-1}$, and ANA=17.7±1.74 cm^2 $year^{-1}$, $p<0.001$). However, ANA exhibited greater sensitivity to climatic variables than AA, displaying increased synchrony in recent years. At the canopy level, a correlation was found between Normalized Difference Vegetation Index (*NDVI*, $r=0.51$, $p<0.05$) and ANA, exclusively. Nonetheless, AA demonstrated a high sensitivity to drought conditions, particularly with the Palmer Drought Severity Index (*PDSI*, $r=0.53$, $p<0.05$). This suggests that prior drought conditions (up to 10 years) are linked to reduced growth in *P. cembroides*, predisposing them to forest pest infestations.

Key words: *Chihuahua*, dendroecology, *NDVI*, *PDSI*, forest pests, drought.

Resumen

Las plagas forestales representan una de las principales causas de disturbio en los bosques templados de México. *Ips confusus* ataca a *Pinus cembroides* después de intensas sequías. El objetivo del presente estudio fue evaluar tanto el impacto por *I. confusus*, como del clima en el crecimiento radial de un bosque de *P. cembroides* en el municipio Carichí, Chihuahua, México. Se obtuvieron núcleos de crecimiento de árboles atacados (AA) y de no atacados (ANA) de la misma especie. Se dataron 53 series dendrocronológicas con una extensión máxima de 1776 a 2012 (AA=24 y ANA=29). A partir de 1998, se observó un crecimiento diferencial en el área basal entre AA y ANA. Al momento de la muerte del arbolado (2012), se registró una diferencia de más de 100 % (AA=8.03±1.53 cm^2 año^{-1}, y ANA=17.7±1.74 cm^2 año^{-1}, p<0.001). Los ANA mostraron una sensibilidad superior a variables climáticas que los AA, con una mayor sincronía en los últimos años. A nivel dosel, se determinó una correlación con el Índice de Vegetación de Diferencia Normalizada (*NDVI*, r=0.51, p<0.05) exclusivamente para ANA. Sin embargo, los AA fueron más sensibles a condiciones de sequía, con base en el Índice de Severidad de Sequia de Palmer (*PDSI*, r=0.53, p<0.05). Esto sugiere que condiciones de sequía previas (hasta 10 años) predisponen menor crecimiento radial de *P. cembroides* y favorece el ataque de plagas.

Palabras clave: Chihuahua, dendroecología, *NDVI*, *PDSI*, plagas forestales, sequía.

Introduction

Globally, forest ecosystems face major challenges such as extreme climate variations, human disturbances, pathogens, and the presence of pests (Lovett *et al.*, 2006; Gómez-Guerrero *et al*., 2021). The latter not only affect wood production (Kurz *et al.*, 2008; Ramsfield *et al.*, 2016), but also ecosystem services such as carbon capture, prevention of soil erosion, water capture and the provision of habitats (Schowalter, 2012). Changing abiotic conditions and changing disturbances often pose a serious threat to forest health (Allen *et al.*, 2010), and when combined with forest insect pests, the consequences can have catastrophic impacts (Breshears *et al.*, 2005).

In Mexico, forest pests represent one of the main causes of disturbance in temperate forests, since it has been recorded that there are around 70 species of insects and pathogens that disturb trees (Semarnat, 2015). Forest health diagnoses and treatments indicate that bark insects are the group of pests that have affected the greatest surface area (40.5 %), among which are *Dendroctonus adjuntus* Blandford, 1897, *Dendroctonus frontalis* Zimmerman, 1868, *Dendroctonus mexicanus* Hopkins, 1905, *Dendroctonus rhizophagus* Thomas & Bright, 1970, among others (Semarnat, 2015). Likewise, one of the main pests of pine trees are the bark beetles of the genus *Ips*, within which some species that are generally considered secondary pests sometimes behave as primary pests, mainly due to the effect of climate change. It is likely that this is related to the stress to which forest ecosystems are subjected due to the effect of more extreme hydrometeorological events and, therefore, a decrease in their resilience, which favors pest attacks (Hernández, 2010; Correa-Díaz *et al.*, 2023).

Insects of the *Dendroctonus* and *Ips* genera are one of the most important mortality factors during forest development (Gillette *et al.*, 2001). In Mexico, *Ips confusus* Wood & Bright, 1992 is distributed in the states of *Baja California*, *Chihuahua*, *Hidalgo* and *San Luis Potosí*, where its main hosts are *Pinus cembroides* Zucc., *Pinus edulis* Engelm., *Pinus monophylla* Torr. & Frém and *Pinus oocarpa* Schiede *ex* Schltdl. (Cibrián *et al.*, 1995). The same authors refer that this beetle attacks *P. cembroides* trees generally after intense droughts, and can behave as a primary pest when conditions favor it. Consequently, they affect a significant number of trees, causing serious damage and mortality to pineon pine forests in transition zones (Floyd *et al.*, 2009). Additionally, Sánchez-Martínez *et al.* (2007) indicate that, at the national level, the *Ips* genus infests trees of the *Pinus* L. and *Picea* A. Dietr. genera without distinction when they are weakened due to droughts, frosts and fires; however, the specimens of these genera, upon recovering from these stress factors, are less susceptible to attack by this pest (Cibrián *et al.*, 1995). Individuals of *I. confusus* establish themselves in wounds, scrapes, and fissures in the lower part of the trunk and at the tip of the crown of adult trees, while the most susceptible hosts are those young *Pinus* specimens in sites with high tree density (Hamilton *et al.*, 2004).

The *Ips* genus, in addition to causing the death of trees, is also associated with the incidence of fungi that stain the wood and, consequently, reduce its commercial value (Cibrián *et al.*, 1995). They make galleries in the phloem and cambium, the male remains in the nuptial chamber and each female builds a gallery arm and forms niches on the sides where they place their eggs. When the larvae are born, as part of the feeding process, they create individual galleries until they transform into a pupa, which is located between the phloem and the cambium (Cibrián *et al.*, 2015).

In 2012, in a natural forest of *P. cembroides* located in the *Pasigochi ejido*, *Carichí* municipality, state of *Chihuahua*, an infestation by *I. confusus* occurred in more than 95 hectares of trees. To combat the pest, sanitation cuts and on-site incineration of the plagued material were carried out. Subsequently, in March 2013, increment cores and cross sections of the attacked trees (AA) and non-attacked or control trees (ANA) of the same species and similar ages were collected, with the aim of: (i) Determine the impact and temporal variation in the growth of *P. cembroides* trees affected by *I. confuses*, and (ii) Estimate the influence of climatic variables on the tree-ring width in the two groups of trees studied (AA and ANA). The above was done through the use of dendrochronological techniques, which allow dating and quantifying with annual precision the disturbances, including the presence of pests that have affected the radial growth of the tree (Swetnam *et al.*, 1985). For example, by comparing ring widths in AA and ANA, it is possible to identify pest attack events over time, as well as infestation regimes (Guiterman *et al.*, 2020). The hypothesis proposed is that through the analysis of tree rings it is possible to identify differentiated behaviors between AA and ANA, prior to the death of the trees. Furthermore, if it is assumed that the effect of *I. confusus* is associated with the presence of droughts, the climatic signal, especially that related to drought indexes contained in the tree rings of AA, should be greater. Given that the decrease in forest resilience due to the effect of drought has been described (Correa-Díaz *et al.*, 2023), the information from this research will be useful to make forest management recommendations after an intense drought event, and minimize the damage that may be caused, in particular, infestations and mortality of trees.

Materials and Methods

Study area

The area is located between 27°54'49" N and -107°12'45" W belonging to the *Pasigochi ejido*, *Carichí* municipality, state of *Chihuahua*, Mexico, where stands of *P. cembroides* are located in areas without forest management (Figure 1). The average altitude of the area is 2 260 m with a dry temperate climate (Bsk) *sensu* Köppen, average annual temperature of 18 °C, precipitation of 450 mm per year and dominance of Regosol type soils (*Comité Técnico Estatal de Sanidad Forestal del Estado de Chihuahua*, 2022).

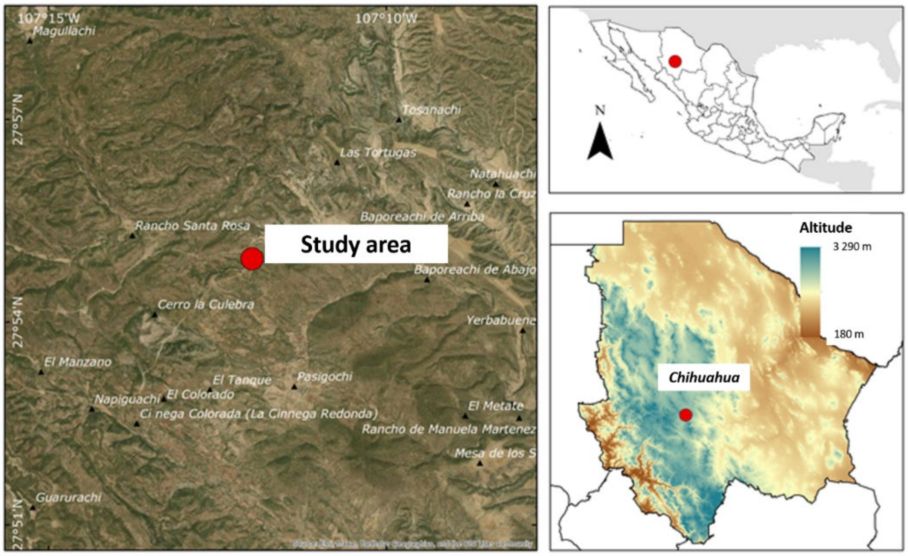


Figure 1. Location of the study area infested by *Ips confusus* Wood & Bright, 1992 in the *Pasigochi ejido*, *Carichí*, *Chihuahua*, Mexico.

Dendrochronological sampling of attacked and non-attacked trees

In March 2013, trees attacked (AA) by *I. confusus* were selected, from which increment cores were obtained with a Haglöf Sweden® Pressler drill of 5.15 mm in diameter and 50.8 cm long (Figure 2A). Additionally, cross sections were collected from individuals felled during the sanitation activities that occurred in 2012. In an adjacent site with dominant vegetation of *P. cembroides* and without apparent damage by *I. confusus*, a second collection of increment cores was carried out (March 2013) for comparative purposes in non-attacked trees (ANA), which served as controls (Figure 2B). In total, 24 AA and 29 ANA were sampled, from which all samples were dated using conventional dendrochronological techniques (Fritts, 1976). The annual growth rings of *P. cembroides* were measured with a VELMEX TA (Velmex Inc., https://www.velmex.com/Downloads/Spec_Sheets/TA%20System%207-1-14%20Rev%20C.pdf) measurement system with a precision of 0.001 mm, in the Dendrochronology Laboratory of INIFAP Cenid-RASPA, located in *Gómez Palacio*, state of *Durango*, Mexico. The crossdating and measurement accuracy of each ring was verified with the COFECHA program (Holmes, 1983). Biological trends not related to climate were removed with the dlpR program (Bunn, 2008) through the standardization process, with a Spline-type curve, which uses a 0.5 frequency at a wavelength of 2/3 of the total length of the series (Cook, 1987). With this, ring width indexes (*IAA*) were generated in their standardized version for AA and ANA. Additionally, with the dplR package, time series of forest productivity were constructed, expressed as Basal Area Increment (*IAB*), which are useful in this type of studies since they relate the amount of wood produced per year (cm^2 year^{-1}) (Biondi and Qeadan, 2008). Since the interest of the study was the plague event that led to the death of a part of the trees in 2012, the analysis focused only on the 1980-2012 period.

A = Obtaining increment cores from *Pinus cembroides* Zucc. affected by *Ips confusus* Wood & Bright, 1992; B = Sampling of non-attacked trees (witnesses) close to the affected area.

Figure 2. Dendrochronological sampling in attacked and non-attacked trees.

Analysis of attacked/non-attacked trees

To quantify the impact of *I. confusus* on the radial growth of *P. cembroides*, the host/non-host analysis was used, which is usually used in dendroecological studies related to forest pests (Swetnam *et al.*, 1985; Lynch, 2012). This analysis consists of comparing the chronologies of the attacked forest species with respect to the non-attacked. In general, the chronology of the unaffected species is subtracted from the chronology of the affected species, once they share a common variance, and thus, a residual index, also called Growth Suppression Index (*GSI*) is quantified, or its standardized version (*NGSI*). When the periods in which this reduction (*NGSI*) exceeds a critical threshold (-1.28 *SD* standard deviation) for several consecutive years, they are considered a product of attack by defoliating insects or pests (Girardin *et al.*, 2001). However, for these events to be defined as widespread attacks throughout the forest, a minimum impact threshold is usually used. In this study, a minimum impact threshold of 45 % of the total trees, present in at least 10 sampled trees, was established. The analysis of pest events was evaluated with the dfoliatR library (Guiterman *et al.*, 2020) in the R program, in the 1980-2012 period.

Effect of climate and photosynthetic activity on tree growth

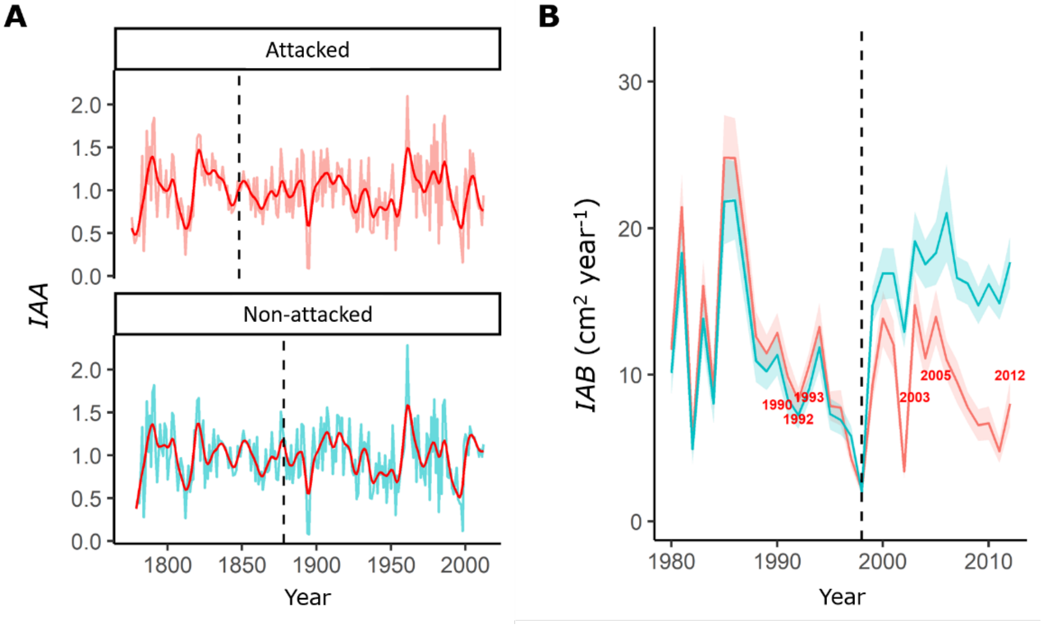
To evaluate the effect that climatic variables have on the growth of AA and ANA, climatic information was downloaded from the study area of the Daymet platform (Thornton *et al.*, 2021), which integrates daily information on maximum and minimum temperature, precipitation, radiation and water vapor pressure for the 1980-2012 period. This information was refined and converted to monthly average values, and then correlated with the *IAA* of AA and ANA using the treeclim package in R (Zang and Biondi, 2015). This package allows obtaining bootstrap-type correlation coefficients (*n*=1 000 replicates). Additionally, to evaluate the stability in the relationships between climate and growth, moving correlations were calculated considering blocks of 25 years starting from 1980.

Finally, the growth information of AA and ANA was correlated with different drought indices (Palmer Drougth Severity Index during June, July and August, $PDSI_{JJA}$; Standardized Precipitation Index, *SPI*) (Stahle *et al.*, 2016; Stahle *et al.*, 2020) and satellite information related to photosynthesis from the Landsat series (Normalized Difference Vegetation Index, *NDVI*) (Huntington *et al.*, 2017). The *NDVI* compares the visible red and near-infrared spectral bands to estimate photosynthetic activity and thus measure the impact of environmental and biotic factors on vegetation. The *NDVI* information was obtained through the ClimateEngine platform (https://app.climateengine.org/), which uses the information available by Google Earth Engine. In this case, the *NDVI* values were generated with the Landsat series, including Landsat 5 to 8 with a resolution of 30 m. For this, stands with homogeneous areas were defined according to the AA and ANA sampling, determining average, minimum and maximum values of *NDVI*, which made it possible to generate *NDVI* time series from 1993 to 2012.

Results and Discussion

Radial growth in attacked and non-attacked trees

A total of 24 dendrochronological series with a temporal extension from 1776 to 2012 were dated for AA, and 29 series for ANA (1779-2012). The average age of AA was 153 years and of ANA 136 years. In both cases, the intercorrelation between series was higher than the threshold value of 0.3281, which ensures good dating quality (AA: *r*=0.67, *p*<0.01; ANA: *r*=0.69, *p*<0.01) (Holmes, 1983). When considering the threshold of Expressed Population Signal (*EPS*)>0.85, the 1848–2012 period was determined as the best replicated for AA (*EPS*=0.96) and 1878–2012 for ANA (*EPS*=0.97) (Figure 3A).



A = Ring width index (*IAA*); B = Basal Area Increment (*IAB*) of *P. cembroides* Zucc. where the shaded areas represent the standard error. The red line in A is a smoothed decade-level curve to highlight periods of low frequency and the dark dashed vertical line indicates an *EPS*>0.85. The dark dashed vertical line in B indicates the year 1998, from which differentiated growth was observed. In B the years with more than 1 000 hectares affected by bark beetles in the state of *Chihuahua* are indicated, according to the Forest Health Management, *Conafor* (median=125 ha).

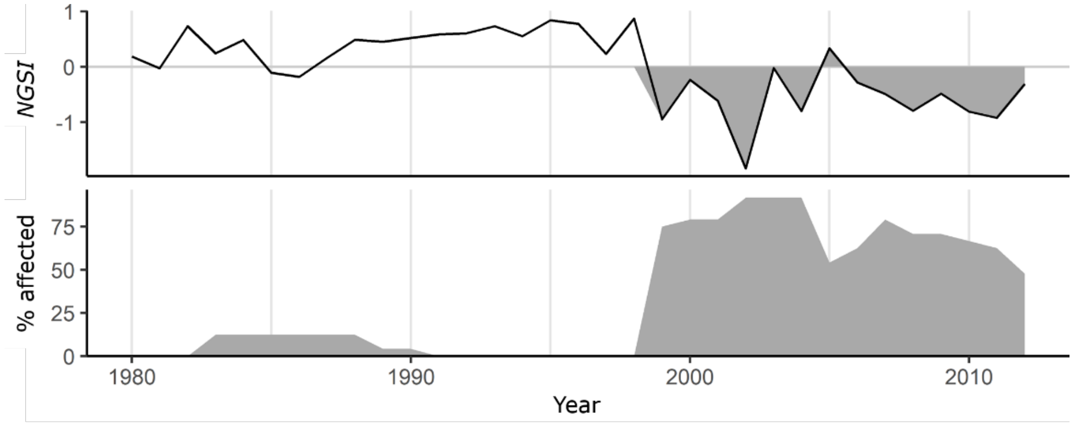
Figure 3. Radial growth in attacked and non-attacked trees.

On average for the 1878-2012 period, the *IAB* of AA and ANA was similar (AA=10.5 ±0.16 cm^2 year^{-1}, ANA=9.86±0.14 cm^2 year^{-1}). However, in recent decades, drought conditions have gradually led to physiological stress in trees with epidemic outbreaks on a larger geographic scale (Cervantes-Martínez *et al.*, 2019; Stahle *et al.*, 2020), especially at from 1998, where a differentiated growth was observed between AA and ANA (Figure 3B). For example, for AA, the trees reduced their growth by 14 %, while ANA increased their growth by more than 50 % with respect to the historical average (AA=9.00±0.40 cm^2 year^{-1}, ANA=15.70±0.48 cm^2 year ^{1}). In this way, at the time of tree death caused by *I. confusus*, a difference of more than 100 % was determined between both conditions (AA=8.03±1.53 cm^2 year^{-1}, ANA=17.7±1.74 cm^2 year^{-1}, p<0.001). Similar results were recorded by López *et al.* (2017), who pointed out a difference in radial increase between *Pseudotsuga menziesii* (Mirb.) Franco trees infested by *I. confusus vs.* healthy trees.

Hammond *et al.* (2021) suggest that signs of mortality in trees usually occur some time after the presence of a drought, although changes in anatomical characteristics are immediate (*e. g.* tree ring, hydraulic conductivity), as observed in the present study. According to the State Technical Committee on Forest Health of the state of *Chihuahua* (*Comité Técnico Estatal de Sanidad Forestal del Estado de Chihuahua*, 2022), in ten *Chihuahua* municipalities (including *Carichí*) there was a high incidence of bark insects in 2012, which affected 90 604.93 ha and a volume to be cleaned of 123 224.25 m^3 roundwood total tree (RTA).

Growth suppression by *Ips confusus*

According to dendrochronological sampling, the AA presented 7 growth suppression events in the 1878-2012 period, lasting up to 8 years. At the end of the 20th century in particular, a notable reduction in growth was observed, confirming the importance of this period for those trees that did not survive. For example, for the last growth suppression event (1998-2012), in 2002 a total of 19 trees (≈80 % of the total) presented the lowest Growth Suppression Index (*GSI*=0.336) or its normalized version (*NGSI*=-1.774) for the maximum extension of the series (Figure 4). Notably, compared to the 1960-1968 period, which was also critical, the percentage of trees affected during the 1998-2012 period was higher, in 2002 in particular (up to 90 % affected). In that year, large areas were harmed by moderate to severe droughts in Northern Mexico and Southern United States (Cook *et al.*, 2009; Stahle *et al.*, 2016). This led to an increase in forest fires and pests in recent decades (Williams *et al.*, 2010).



Normalized Growth Suppression Index (*NGSI*) with growth reduction events in gray (below zero). Values less than -1.28 are considered critical events. The lower panel shows the percentage of affected trees (*n*=24).

Figure 4. Growth suppression by *Ips confusus* Wood & Bright, 1992.

Association of tree growth with climatic variables

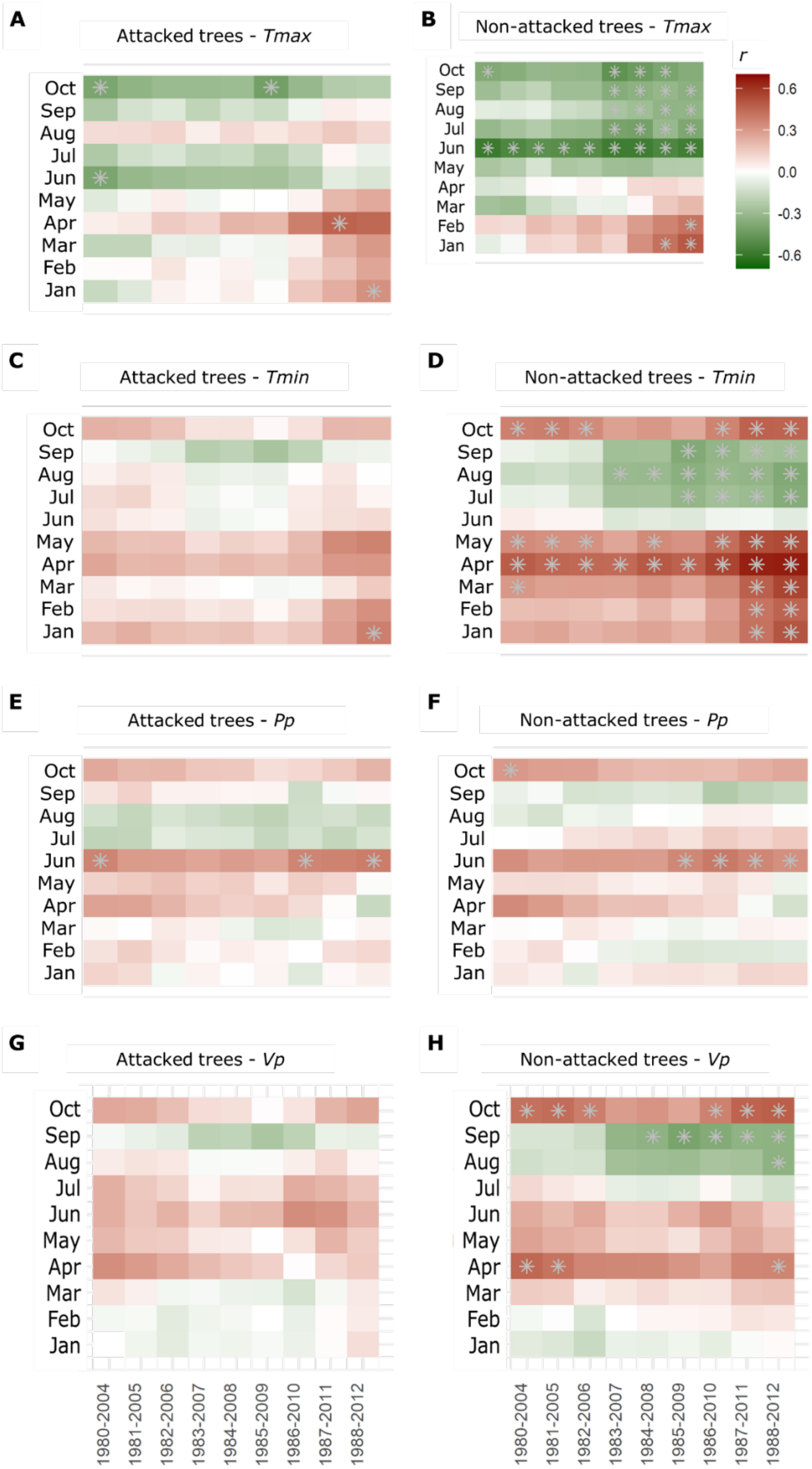
The characteristics that predispose forest species to bark beet attack are multiple, including structural attributes, ecological and climatic conditions (Müller *et al.*, 2022). In general, ANA showed greater sensitivity to climatic variables than AA. For example, minimum temperature was positively correlated with *IAA* during March to May (r=0.36 to r=0.53, p<0.05) (Table 1). A negative association was observed with the maximum temperature from September to October prior to the growing year and with water vapor pressure (April), although exclusively for ANA (Table 1). No significant correlations were found between the *IAA* of the AA and the climatic variables analyzed.

Table 1. Pearson correlation coefficient (Bootstrap n=1 000) between climatic variables and ring width indices of attacked (AA) and non-attacked (ANA) trees.

Month	**Maximum temperature**		**Minimum temperature**		**Precipitation**		**Water vapor pressure**	
	AA	**ANA**	**AA**	**ANA**	**AA**	**ANA**	**AA**	**ANA**
Prev. Sep.	---	-0.424	---	-0.385	---	---	---	-0.367
Prev. Oct.	---	-0.415	---	---	---	---	---	---
March	---	---	---	0.355	---	---	---	---
April	---	---	---	0.531	---	---	---	0.388
May	---	---	---	0.410	---	---	---	---
June	---	-0.490	---	---	---	---	---	---
October	---	---	---	0.422	---	---	---	0.400

Values are significant correlations (p<0.05). Prev. = Months prior to the year of growth.

Moving correlations confirmed the greatest association between ANA and climate variables. This type of analysis not only allows identifying key months for the growth of the tree, but also its stability/change over time (Zang and Biondi, 2015). For example, in addition to the significant correlation in June with maximum temperature (r=-0.60, p<0.05), a correlation was observed from July to October in recent years (Figure 5A and 5B). This trend was also observed with minimum temperature, particularly due to a positive effect from January to March (r=0.64, p<0.05) and a negative effect from July to September (r=-0.43, p<0.05) (Figure 5C and 5D).


A
Attacked trees - *Tmax*
B
Non-attacked trees - *Tmax*
C
Attacked trees - *Tmin*
D
Non-attacked trees - *Tmin*
E
Attacked trees - *Pp*
F
Non-attacked trees - *Pp*
G
Attacked trees - *Vp*
H
Non-attacked trees - *Vp*
Oct
Sep
Aug
Jul
Jun
May
Apr
Mar
Feb
Jan
r
0.6
0.3
0.0
-0.3
-0.6
1980-2004
1981-2005
1982-2006
1983-2007
1984-2008
1985-2009
1986-2010
1987-2011
1988-2012

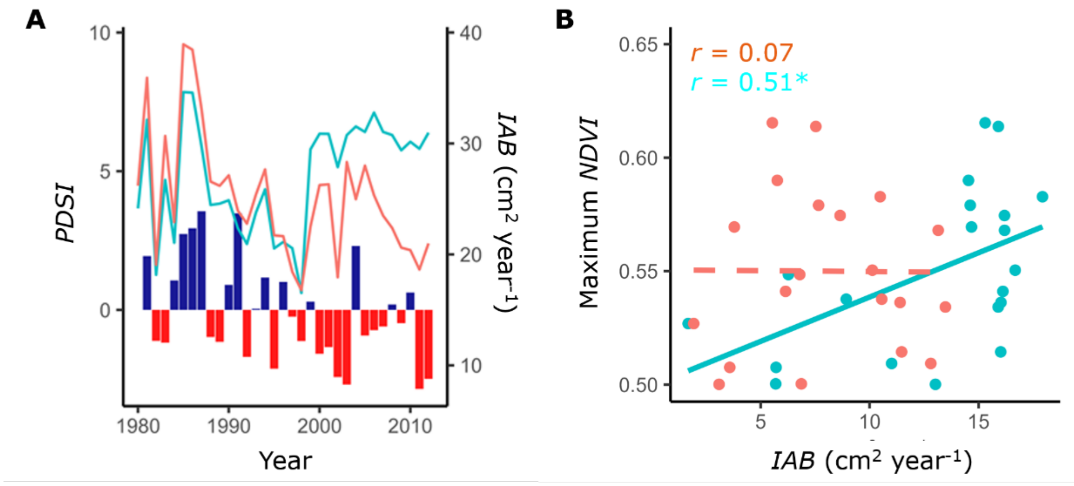
Tmax = Maximum temperature; *Tmin* = Minimum temperature; *Pp* = Precipitation; *Vp* = Water vapor pressure. **p*<0.05.

Figure 5. Moving correlations (1980-2012) between attacked (AA) and non-attacked (ANA) trees.

Although the stationary correlations (Table 1) did not show any significant association with precipitation, the analysis of moving correlations showed that since 1985, there is a positive and consistent correlation in June (r=0.39, p<0.05) (Figure 5F). Likewise, for September with water vapor pressure (r=-0 41, p<0.05) (Figure 5H).

Influence of drought conditions and their effect on canopy photosynthetic activity (*NDVI*)

Drought events affected the growth of *P. cembroides*, but unlike climatic variables that were only correlated with ANA, a positive association was found between $PDSI_{JJA}$ (June to August) and *IAB* in AA (r=0.53, p<0.05). Similarly, a positive correlation was verified between *SPI* and *IAB* in AA (r=0.38, p<0.05), although not for ANA (Figure 6A). These values confirm that drier conditions are linked to reductions in growth in the AA of *P. cembroides*, which constitute favorable conditions for the attack of *I. confusus* due to its greater sensitivity to drought. This behavior has been corroborated by Cervantes-Martínez *et al.* (2019), who mention that the year with the highest tree mortality due to bark beet attack is related to drought conditions that occurred in up to five previous years, although in this study, it was found that the effect of drought can last up to a decade. Therefore, it is important to detect years with below-average rainfall, since there is a significant association between bark beetle outbreaks and drought conditions, particularly detected by the *PDSI* and circulatory phenomena such as ENSO (Cervantes-Martínez *et al.*, 2019).



A = Influence of the Palmer Drought Severity Index (*$PDSI_{JJA}$*) on the Increase in Basimetric Area (*IAB*); B = Scatter plot between Increase in Basimetric Area (*IAB*) and maximum *NDVI* per year. Red represents attacked trees and blue represents non-attacked trees.

Figure 6. Effect of drought and photosynthetic activity on the radial growth of *Pinus cembroides* Zucc.

In the case of the correlation with *NDVI*, ANA showed a greater association with annual maximum *NDVI* (r=0.51, p<0.05) and annual average *NDVI* (r=0.39, p<0.05), compared to AA. This shows a synchrony between growth and maximum summer photosynthetic activity, but only in those trees that were not stressed by the *I. confusus* attack (Figure 6B). These results identified a change in the spectral signal associated with insect damage, suggesting that due to the stress to which AAs are subjected there is a low correlation with the *NDVI*. In general, it is recognized that dense and healthy vegetation should present values above 0.5. In this study, the interval 0.5-0.65 was determined as the maximum *NDVI* values associated with healthy vegetation, hence the correlation with the attacked trees is low (*r*=0.07), unlike the non-attacked trees that were mostly correlated (*r*=0.51) in this range.

Hamilton *et al.* (2004) have suggested this relationship as a strategy to monitor the impact of *I. confusus* on large surfaces in the Southern United States. In this way, the stress produced by disturbances such as drought, fires or pest attacks affects the biophysical and biochemical properties of the tree, which is reflected in a change in the spectral trait (Lausch *et al.*, 2016). The *NDVI* allows us to identify these spectral changes manifested as the defoliation of trees, the change in chlorophyll fluorescence and the decrease in water content in the needles due to water stress caused by bark beetle damage (Gomez *et al.*, 2020).

Conclusions

The use of dendrochronology in the study of the impact of the bark beetle *I. confusus* demonstrated that extreme drought events, such as the one that occurred in 1998, are a highly significant trigger in the mortality of stone pine (*P. cembroides*) individuals in a locality from the *Carichí* municipality, *Chihuahua*, Mexico. Unaffected trees responded negatively to the maximum temperature, and positively to the minimum temperature, which is probably related to a lower water demand. However, affected trees showed greater sensitivity to drought indices, which implies a negative effect on growth and, therefore, greater vulnerability to pest attack. Extreme drought events prolonged their effect for up to 10 years, which reduced the capacity of trees to recover from external disturbances, which was observed in the differential behavior between growth series between attacked and non-attacked trees. The effect of these droughts can be capitalized to take preventive measures against events of this magnitude in order to minimize their effect, which may be more frequent due to global warming.

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Conflict of interest

The authors declare no conflict of interest. Arian Correa Díaz, as Section Editor of the Revista Mexicana de Ciencias Forestales states that he did not participate in the editorial process of the article.

Contribution by author

Luis Ubaldo Castruita Esparza and José Villanueva Díaz: field logistics and laboratory analysis; Arian Correa Díaz: programming; Arian Correa Díaz, Rosalinda Cervantes Martínez and Alma Delia Ortiz Reyes: data analysis and writing of the manuscript.

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