

Response to climate and influence of ocean-atmosphere phenomena on annual radial increments of *Pinus oocarpa* Schiede ex Schltdl. & Cham in the Lagunas de Montebello National Park, Chiapas, Mexico

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The Lagunas de Montebello National Park, Chiapas, Mexico, is one of the most important protected areas in terms of ecology and the provision of ecosystem services in the state of Chiapas; however, it lacks long-term climate information to support comprehensive plans for the conservation of endangered species and ecosystem restoration actions. The objectives of this work were to analyze: (i) the interannual variability of the annual rings of *Pinus oocarpa* Schiede in the Lagunas de Montebello National Park, as influenced by climate; and (ii) the ocean-atmosphere phenomena influence on both the interannual variability of the total ring-width series. A dendrochronological series of *P. oocarpa* was built for the period 1857-2018 (162 years), which indicates the presence of extreme hydroclimatic events in the region. Of these, the 1998 drought was a milestone for the management of this natural area due to the high-intensity fires that affected the area and caused unprecedented ecological, social, and economic damage in the site history. The climatic variables with the greatest influence on the annual radial increase of the species are precipitation and maximum temperature in winter-spring, when growth is positively associated with precipitation and negatively associated with temperature, attributed to increases in evapotranspiration. El Niño Southern Oscillation was the phenomenon with the highest correlation with climatic variability and the radial growth of the species, in frequencies of less than five years, although the positive influence of the Atlantic Multidecadal Oscillation was also assessed annually. Global warming, characterized by increasing temperature, threatens the persistence of plant communities in the study area; therefore, knowing its impact on the growth of species of economic importance is essential to support conservation actions.

Keywords: Dendrochronology, Hydroclimatic Variability, Drought, *Pinus oocarpa*

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Received: Apr 10, 2022 - Accepted: Mar 21, 2023

Citation: Ponce-Calderón LP, Villanueva-Díaz J, Rodríguez-Trejo DA, Bilbao BA, Álvarez-Gordillo GDC (2023). Response to climate and influence of ocean-atmosphere phenomena on annual radial increments of *Pinus oocarpa* Schiede ex Schltdl. & Cham in the Lagunas de Montebello National Park, Chiapas, Mexico. *iForest* 16: 174-181. - doi: [10.3832/ifor4112-016](https://doi.org/10.3832/ifor4112-016) [online 2023-06-30]

Communicated by: Angelo Rita

Introduction

Biocultural diversity in the Lagunas de Montebello National Park (PNLM, in Spanish) is essential to support its protection and conservation. This area is home to several plant species listed as priorities for conservation, including several orchids (*Epidendrum coririfolium* Lind., *Maxillaria elatior* Rchb. f.), and bromeliads (*Tillandsia carlsoniae* L.B.Sm., *T. eizii* Lyman B. Smith – Beutelspacher & Moreno-Molina 2011). Some of the tree species are included in the Red List of the International Union for Conservation of Nature (IUCN), such as *Quercus crassifolia* Humb. & Bonpl., *Quercus sapotifolia* Liebm., *Quercus elliptica* Née, *Pinus oocarpa* Schiede, and *Pinus maximinoi* H.E. Moore. Additionally, the PNLM has been designated as a RAMSAR site and integrated into the World Network of Biosphere Reserves due to the importance of its wetlands and lakes of karst origin, which are sites of unparalleled scenic beauty and valuable provision for ecosystem services to the region (CONANP 2007, Mora et al. 2016).

The presence of *P. oocarpa* in the conifer

forest with shallow soil and annual precipitation below 1200 mm characterizes this vegetation type in the PNLM (CONANP 2007). Although rainfall may not be a limiting factor for the development of this species, the karst condition of the site characterized by the dominance of shallow low-fertility soils contributes to both limited water and nutrient availability, thus affecting the annual radial growth and enhancing the interannual variability in the annual rings of *P. oocarpa* (Szejner 2011).

Despite long-lived trees have been removed for forest logging or eliminated by strong fires and pests that have occurred in the region (Ponce-Calderón et al. 2021), long-lived pine individuals are still found in hard-to-access forest patches of Chiapas, Mexico, and Guatemala. These specimens can be used to construct dendrochronological series covering a period up to 200 years or more, beyond the extent of the available climatic records. This is a viable alternative to produce a better understanding of hydroclimatic variability in the study area, and to determine the presence and frequency of extreme hydroclimatic events

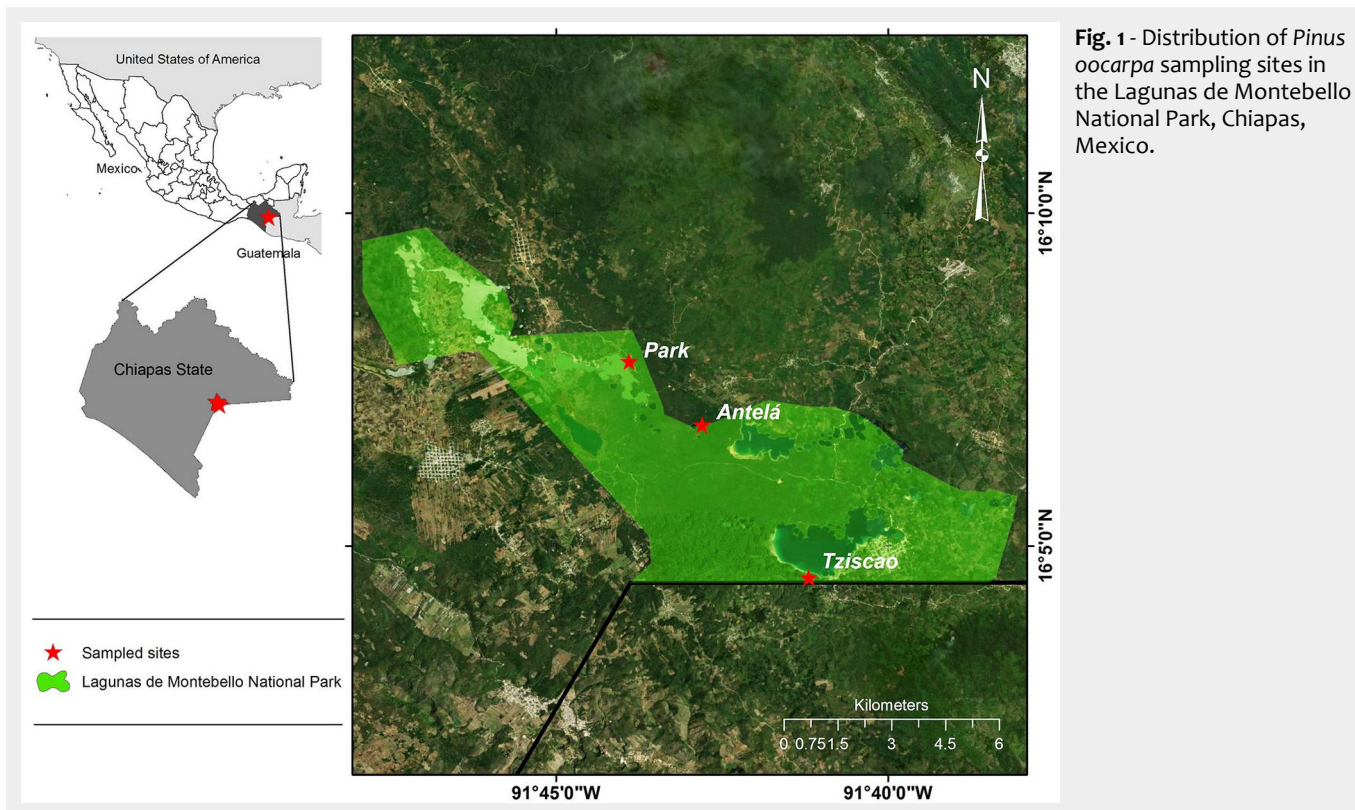


Fig. 1 - Distribution of *Pinus oocarpa* sampling sites in the Lagunas de Montebello National Park, Chiapas, Mexico.

and their trends over time; this is key to supporting biodiversity management and conservation plans in this area.

Knowledge of the variability of seasonal climatic factors such as precipitation and temperature is essential both for developing management strategies for conservation and implementing mitigation actions in case of extreme hydroclimatic events (Villanueva-Díaz et al. 2021). To this end, one of the resources used for assessing the impact of the future climate is the historical and current behavior of global circulation patterns. These simulate physical processes in the atmosphere and provide support to predictive climate models (Conde 2003).

The information derived from tree rings is used to capture the variability in climate series and their historical frequency and trends, which are useful for determining the fluctuations of extreme hydroclimatic events and changes in climate behavior due to global warming (Villanueva-Díaz et al. 2021). This approach can provide information to respond to the challenges of climate change and set technically based actions for the conservation and restoration of biodiversity in this and other regions of Mexico and the world (Tomazello et al. 2009). This place is potentially vulnerable to climate change and wildfire risk, whose effect may be greater in areas of higher biological diversity included in conservation projects (Manzo-Delgado & López-García 2020).

The objectives of the present study are to analyze: (i) the interannual variability of the annual rings of *P. oocarpa* in the PNLM as influenced by climate; and (ii) the ocean-

atmosphere phenomena influence on both the interannual variability of the total ring-width series.

Materials and methods

Description of the study area

Sites representative of the coniferous forest were located within and outside the PNLM (Fig. 1). The first site is “Antelá”, located at 16° 06′ 48.8″ N, 91° 42′ 47.9″ W at an elevation of 1556 m a.s.l., in the municipality of Trinitaria, Chiapas, Mexico, adjacent to the PNLM; the site is dominated by mixed forest vegetation composed of pine-oak-sweetgum. The second site is “Tziscão” (16° 04′ 31.1″ N, 91° 41′ 11.7″ W; 1547 m a.s.l.), located within the PNLM and covered by a sweetgum-pine-oak forest. The third site, “Park” (16° 07′ 45.9″ N, 91° 43′ 53.8″ W; 1467 m a.s.l.), comprises part of the municipalities of La Independencia and La Trinitaria, Chiapas; it is located within the core area of the PNLM and has dominant vegetation of pine-oak-sweetgum. The coniferous species present in the area include *Pinus maximinoi*, *Pinus tecunumanii* F. Schwardt. ex Eguliz & Perry, *Pinus teocote* Schiede ex Schltdl. & Cham., *Pinus devoniana* Lindl., and *Pinus oocarpa*, the latter being the dominant conifer species in the area and, in general, in the region (CONANP 2007). The dominant oak species are *Quercus benthamii* A.DC, *Quercus laurina* Humb. & Bonpl., and *Quercus candicans* Née (Rzedowski 2006, Ramírez-Marcial et al. 2010). The prevailing soils are classified as Lithosols, Rendzinas, Vertisols, Acrisols, Fluvisols, and Gleysols (INEGI 2000). Lithosols and Rendzinas prevail across most of

the park and are dominant in steep slopes and hills, with very shallow soils prone to erosion and low moisture retention. Rendzinas also occupy gentler sloping sites. These soil types are deeper, with good fertility, and allow an adequate rooting of trees (Vásquez & Méndez 1994).

Climate data

The PNLM comprises an elevation range of 1500 to 1800 m.a.s.l. According to García (2004), the climate is of type C(fm), humid temperate with rains throughout the year, with a mean monthly temperature of 22.6 °C and mean annual precipitation in the range of 1200 to 1400 mm. The period with the highest precipitation spans from June to September (summer season). There are no climatic records from meteorological stations located directly in the PNLM, so the climate variability was extrapolated from the “La Trinitaria” meteorological station (16° 07′ 04″ N, 92° 03′ 06″ W; 1540 m a.s.l. – Fig. 2), located 32 km away from the study site in straight line that, due to its proximity, altitude, and similarity in ecological conditions, is considered representative of the climatic conditions characterizing the PNLM.

Climate data (1901-2013) from the ClimateNA database (Wang et al. 2016), and a database for the period 1950-2015 of climatic stations of the National Meteorological System available in a 0.1° x 0.1° grid. Missing data were estimated by interpolation based on the existing data and Thiessen polygons (Terán-Cuevas 2010), seasonal precipitation data (1892-2016) from the North American Seasonal Precipitation Atlas (NASPA – Stahle et al. 2020), and

drought indices (1870-2012) obtained from the Mexican Drought Atlas (MXDA – Stahle et al. 2016).

Sampling procedure

At each sampling site, several individuals of *P. oocarpa* were chosen by including the largest number of mature and long-lived specimens and approximately 10% of young individuals, distributed over a large part of the study basin and, at the same time, representative of the dominant climatic conditions of the PNLM. Tree-ring series for *P. oocarpa* have been previously developed in Mexico and Guatemala, where the formation of annual rings and their response to limiting climate conditions have been demonstrated (López-Hernández et al. 2018, Villanueva Díaz et al. 2018).

Although *P. oocarpa* forms annual rings, the period where the formation of annual rings is completed is not well understood. Results from a dendrochronological study done with this species in Eastern Guatemala indicates the activation of cambial activity with the first rains of April and May, earlywood formation may end with the mid-summer drought (July-August), be reactivated in September when the late-wood formation starts forming and ending by November (Szejner 2011).

From each sampled tree, 2 to 3 increment cores were drilled at breast height (1.30 to 1.40 m) with a Pressler bore of variable dimensions (20.0 to 45.0 cm) and 5.1 mm inner diameter. Each individual was georeferenced and the presence of fire scars, wounds, incidence of pests, and some other ecological variables of the microsite were noted; these data are useful to explain growth anomalies, which could be evidenced during the dating of annual increments.

Overall, 102 trees were sampled, 43 in Antelá, 33 in the Park, and 26 in Tzisco, from which two increment cores per tree were obtained totaling 204 increments. Additionally, 187 cores were collected from 83 trees, which were used for an age structure analysis carried out for the same study sites. Also, 10 cross-sections obtained from dead individuals or from stumps found scattered across the study area were obtained, for a total of 401 samples from 195 trees for dendrochronological dating.

Tree-ring series development

Samples were dried at room temperature, then polished with sandpaper of different grains (coarse to fine) to delimit annual growth rings. After pre-dating, the ring widths were measured in a Velmex system to the nearest 0.001 mm. Dating quality was determined with the COFECHA program (Holmes 1983). To eliminate the influence of an increasing diameter, the measured series were standardized with the ARSTAN program by applying a double standardization procedure to the data: first, a negative exponential or regression line; second, a flexible curve (spline) com-

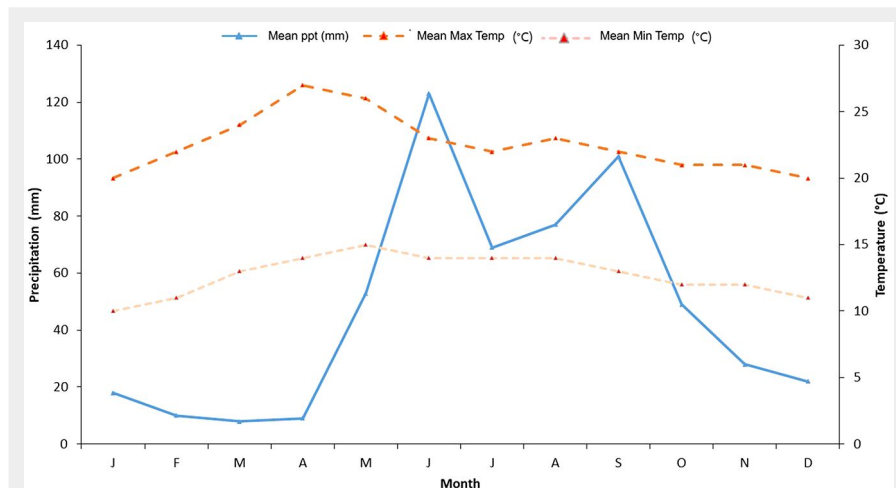


Fig. 2 - Climogram of the “La Trinitaria” meteorological station, Chiapas. (PPT): precipitation (mm); (Max Temp): maximum temperature (°C); (Min Temp): minimum temperature (°C).

prising 128 years that preserves 50% of the variance (Cook & Holmes 1984). This process yielded three versions of the chronology, namely standard, residual, and arstan, each generated through different statistical processes (Cook & Holmes 1984). The residual chronology, in which the autocorrelation between ring-width series was eliminated by a robust mean, was used as a proxy of the interannual climate variability of the PNLM in the extension of the chronology, where the number of increment cores indicated statistical reliability for the purposes of climate reconstruction and determined by an Expressed Population Signal (EPS) value higher than 0.85 (Wigley et al. 1984). Likewise, various dendrochronological parameters were selected to determine the potential of the chronology for dendroclimatic reconstructions, such as the intercorrelation between series, mean sensitivity, and first-order autocorrelation.

Climate response function and influence of large-scale circulation modes

To analyze the response of the total ring-width chronology to climate, we used a Pearson correlation approach by contrasting the tree-ring series with several climate databases, including weather records from the Trinitaria station. To assess the influence of large-scale ocean-atmosphere modes on the behavior of the total dendrochronological series, this was compared with El Niño Southern Oscillation (ENSO) indices, that is, the Multivariate ENSO Index (MEI), an indicator that combines oceanic and atmospheric variables to estimate an index of ENSO variability (Wolter & Timlin 2011), and El Niño Ocean Index (ONI), a measure of the condition of El Niño-Southern Oscillation and its warm (El Niño) and cold (La Niña) phases in the Central Equatorial Pacific (Glantz & Ramirez 2020). Similarly, Pearson’s correlation values were obtained when comparing the ring-width chronology with indices of the Atlantic

Multidecadal Oscillation (AMO – Endfield et al. 2001), a quasi-periodic climate variation from 50 to 70 years centered on the Atlantic region, and the Pacific Decadal Oscillation (PDO – Mantua et al. 1997), a recurrent pattern of ocean-atmosphere climate variability above 20° in the Pacific Ocean basin.

The total dendrochronological series, which constitutes an indirect source of climate variability, was plotted over the total period of time studied, with a mean close to unity (≈ 1.0), where values above (> 1.0) and below (< 1.0) the mean represent wet and dry conditions, respectively (Fritts 1976). In the ring-width chronology, extreme hydroclimatic events were those with a standard deviation below (extremely dry) or above the mean (extremely wet – Manrique & Fernandez-Cancio 2000).

To assess the influence of general circulation modes, the presence of significant peaks in this series was determined by a power spectral analysis (Grinsted et al. 2004); the periods in which the dendrochronological series indicates the significant influence of these phenomena were determined by a wavelet spectral analysis performed in R (Tarik et al. 2017).

Results

Dendrochronological series

Of a total of 401 increment cores, 157 (39% of the total samples) were suitable for dating, although the number of cores per year to estimate the ring-width indices varied along the extent of the chronology, with a sample size of 5 cores after 1890 (Fig. 3).

The dendrochronological series span over the period 1857 to 2018 (162 years), with a series intercorrelation of 0.399, which is higher than the minimum value required to be considered adequately dated ($r = 0.328$, $p < 0.01$). The mean sensitivity was 0.491, and the first-order autocorrelation was 0.4369, indicating that the growth of the

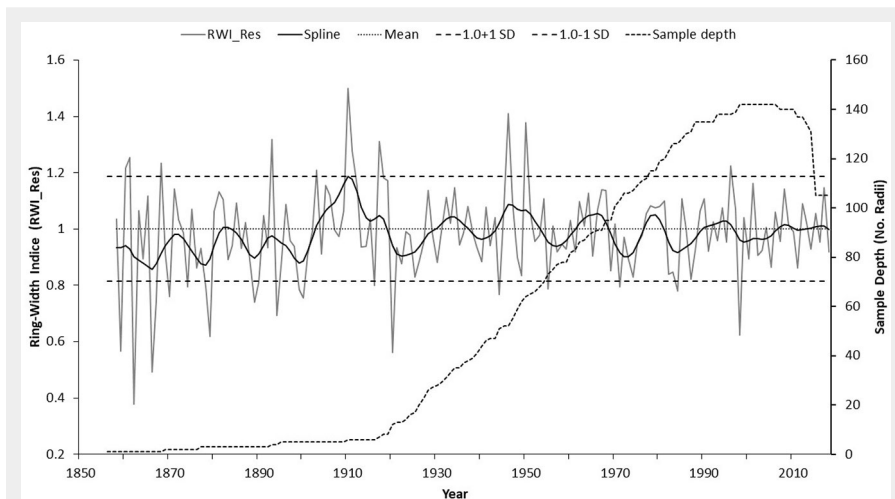


Fig. 3 - Residual version of the ring-width chronology with sample depth showing extreme hydroclimatic events (wet and dry) based on one standard deviation above and below the mean, respectively.

> 0.05), December ($r = -0.18, p < 0.05$), January ($r = -0.13, p > 0.05$), February ($r = -0.16, p > 0.05$), March ($r = -0.20, p < 0.05$), April ($r = -0.28, p < 0.01$), May ($r = -0.23, p < 0.05$), and June ($r = -0.21, p < 0.05$), and seasonally for the mean maximum temperature in November-June ($r = -0.29, p < 0.01$).

In relation to La Trinitaria meteorological station, the maximum monthly temperature for 1992-2015 was negatively associated with the ring-width indices. Significant correlations occurred in June ($r = -0.40, p < 0.05$), July ($r = -0.52, p < 0.01$), and August ($r = -0.56, p < 0.01$) of the current growth year and the mean maximum temperature in June, July, and August ($r = -0.53, p < 0.01$). The associations between the total ring-width chronology and the precipitation and maximum temperature records for La Trinitaria meteorological station are shown in Fig. 4.

Extreme hydroclimatic events in the dendrochronological series

The response of the chronology to climatic variables (precipitation, maximum temperature), supported that dendrochronological indices can be used as a proxy or indirect method of climatic conditions that have influenced the PNLM over the Past 162 years (1857-2018) and that extreme events evidenced as one standard deviation above or below the mean (1.0) correspond to wet and dry years, respectively. Based on the above, suitable climatic conditions occurred in years 1860, 1861, 1868, 1893, 1910, 1911, 1917, 1918, 1919, 1946, 1950, and 1996; whereas limiting climatic conditions occurred in 1859, 1862, 1866, 1870, 1889, 1890, 1894, 1899, 1900, 1917, 1920, 1955, and 1998; the latest (1998) was a milestone in the management of the PNLM because of devastating fires in the region (Fig. 5).

Relationship between tree ring-width to large-scale ocean-atmosphere circulation modes

The association between the total ring-width chronology and various ENSO indices indicated a significant relationship ($p < 0.05$) for the MEI (1951-2017) in February ($r = -0.25$), March ($r = -0.25$), April ($r = -0.24$), and May ($r = -0.27$) of the current growth year (Fig. 6). A similar behavior was observed for the ONI index (1951-2018), with correlations in January ($r = -0.20, p > 0.05$), February ($r = -0.23, p < 0.05$), March ($r = -0.23, p < 0.05$), and April ($r = -0.21, p > 0.05$) of the current growth year.

The smoothed AMO indices for the period 1920-2010 showed a significant association with the total ring-width indices ($r = 0.21, p < 0.05$), but only when considering the annual mean, suggesting that this phenomenon also influences tree growth in this region, although to a lesser extent relative to ENSO.

With regard to the association between PDO indices and total ring-width chronology indices in the period 1902-2012, we did

current year is influenced by the growth of the previous year, which is common for the vast majority of conifers and other broad-leaves in Mexico. The EPS value was higher than 0.85 from the early to the most recent part of the chronology. Therefore, the total series is considered statistically robust for climate reconstruction purposes and to analyze its influence on the radial growth of the species (Fig. 3).

Response of the chronology to climate variables

The relationship between total ring-width chronology and data from the regional precipitation grid, comprising the PNLM over the period 1953-2013 showed positive associations in April ($r = 0.35, p < 0.01$), May ($r = 0.19, p < 0.05$), and June ($r = 0.17, p < 0.05$) and the May-June cumulative period ($r = 0.24, p < 0.05$). A similar behavior was observed with shorter precipitation records (1992-2015; 24 years) from the La Trinitaria

meteorological station, with a positive response in February ($r = 0.43, p < 0.05$), March ($r = 0.17, p > 0.05$), April ($r = 0.18, p > 0.05$), May ($r = 0.15, p > 0.05$), and seasonally for February-May ($r = 0.32, p > 0.05$).

Instrumental precipitation records for the 1980-2014 December-April season (35 years), obtained from NASPA (Stahle et al. 2020) indicate a significant association with the total ring-width residual chronology ($r = 0.43, p < 0.01$). Precipitation data from ClimaNA showed no significant association in any of the 18 months in the comparison (6 months prior to the growth year and 12 months during the growing season). Based on these results, the period when the species shows a positive response to precipitation corresponds to the winter-spring season.

Regarding maximum temperature, the ClimaNA database (1901-2013) showed a negative association with the total ring-width chronology in November ($r = -0.15, p$

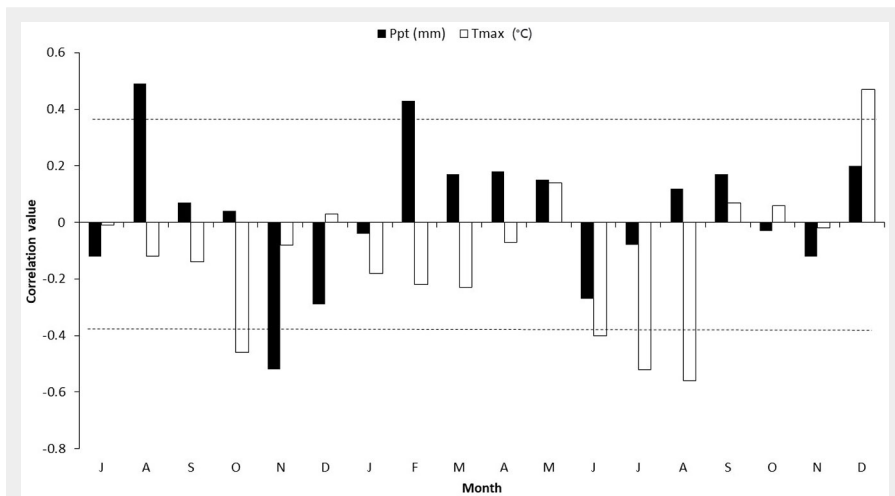


Fig. 4 - Correlation values between the dendrochronological series of total ring-width (residual version), monthly precipitation (Ppt in mm) and monthly mean maximum temperature (Tmax in °C) records for La Trinitaria meteorological station.

not find any significant relationship ($p < 0.05$), which may indicate the lack of influence of this phenomenon on the radial growth of *P. oocarpa* in the PNLM.

The analysis of the spectral peaks in the regional dendrochronological series of the PNLM indicates significant frequencies in periods of 4.5, 3.69, and 2.18 years, respectively (Fig. 7).

Discussion

The response of the ring-width chronology to climatic variables (precipitation, maximum temperature), supported that dendrochronological indices can be used as a proxy or method of predicting dominant climatic conditions that have characterized the PNLM over the past 162 years (1857-2018), and that extreme events evidenced as one standard deviation above or below the mean (1.0) correspond to wet and dry years, respectively.

The significant peaks detected in the ring-width chronology are located within the high frequency range of ENSO (5.0, 3.8, 2.5 years), a situation that confirms the significant relationship between total ring-width indices and MEI and ONI indices of this circulatory phenomenon. This behavior is verified through a wavelet analysis, which shows that periods when this phenomenon exerted a significant influence occurred throughout the chronology (Fig. 7).

The development of ring-width chronologies of *P. oocarpa* requires a large sample-size in comparison to other more climate-sensitive conifer species such as *Pinus cembroides* and *Pseudotsuga menziesii* characterized by interseries correlations > 0.7 (Constante et al. 2009). *P. oocarpa* showed frequent growth-ring releases and compression episodes, as well as false rings, which may be intrinsic to the species or associated with the seasonality of precipitation, forest density, and other human-induced disturbances (Taccoen et al. 2021).

Precipitation in winter-spring has a positive effect on the annual radial increment; however, rises in mean monthly maximum temperature in spring and summer along with higher water availability in tropical ecosystems exert an adverse effect on net primary productivity, attributed to an increase in evapotranspiration. This may result in greater vapor-pressure shortages, less growth, and ultimately in dieback and mortality due to the greater susceptibility of trees to pests and diseases (Allen et al. 2010, McDowell & Allen 2015). On the other hand, higher temperatures imply a higher evapotranspiration rate and, therefore, lower biomass production (Ryan et al. 1995).

The positive effect of cumulative seasonal precipitation in winter-spring and the negative effect of rises in temperature during the growing season has been reported for various species of conifers in temperate forests of north-central and southern Mexico (Aquino-Ramírez et al. 2019, Carlón-Alende et al. 2020, Manzanilla-Quiñonez et

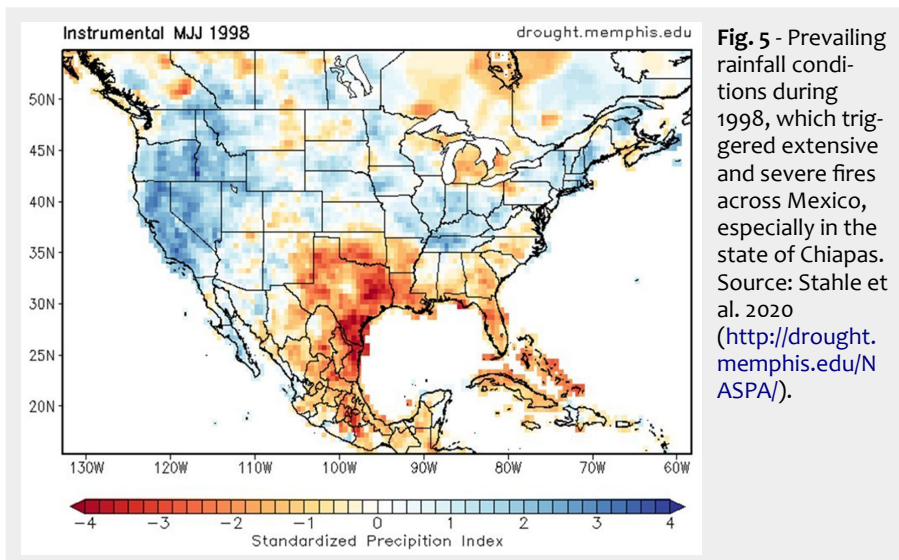


Fig. 5 - Prevailing rainfall conditions during 1998, which triggered extensive and severe fires across Mexico, especially in the state of Chiapas. Source: Stahle et al. 2020 (<http://drought.memphis.edu/NASPA/>).

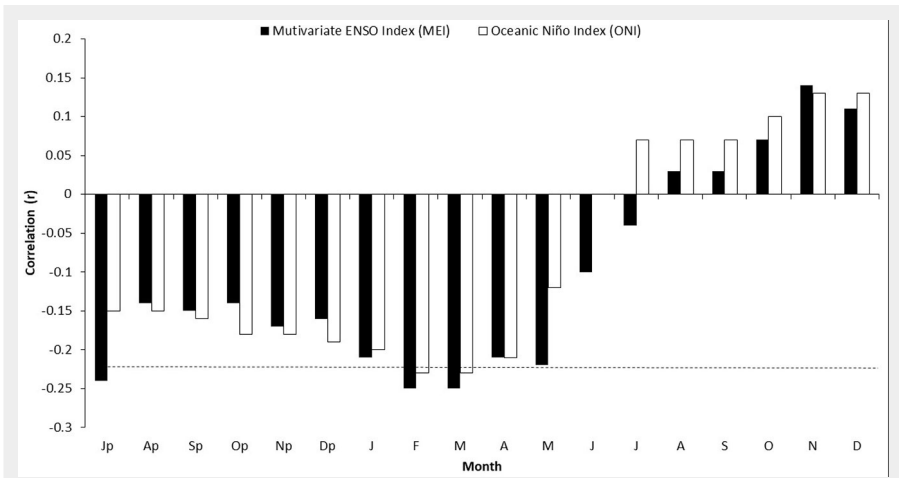


Fig. 6 - Response of the ring-width chronology of *P. oocarpa* in the Lagunas de Montebello National Park and ENSO indices (MEI, ONI). Months with a lowercase letter (p) belong to the previous years of growth.

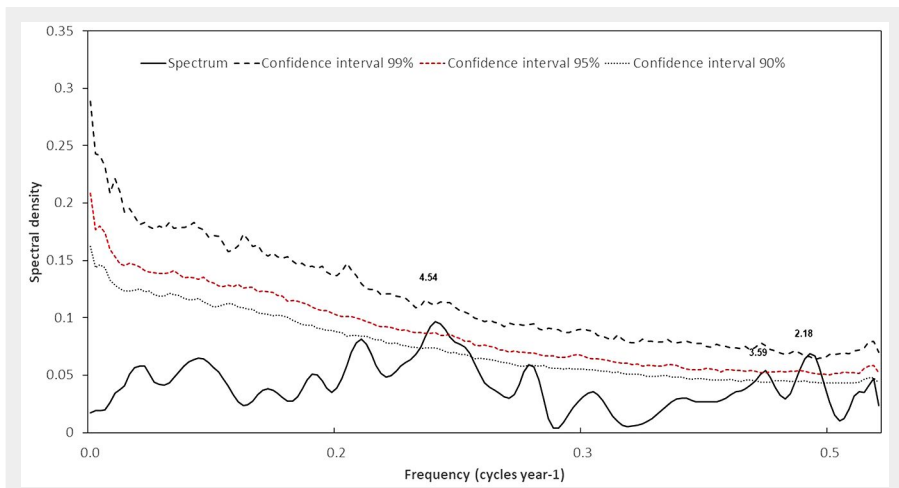


Fig. 7 - Wavelet power analysis of total ring-width series residual version of *P. oocarpa* in the PNLM. The peaks framed by the red line are significant at 95%.

al. 2021, Villanueva-Díaz et al. 2021). The relationship between the total ring-width series of *P. oocarpa* in the PNLM and precipitation and temperature data indicates that the chronology generated is a proxy of the prevailing climatic conditions in the area. Historical information on drought events at the national level indicates extreme dry periods in Chiapas from 1866 to 1870, 1887, and 1899 (Contreras

2005). Droughts recorded at national level, such as those occurred in the decades 1870, 1890, and 1950, also impacted the state of Chiapas, with adverse effects on food production (Florescano et al. 1980, Domínguez 2016).

The most devastating drought in the state of Chiapas, particularly for the PNLM, occurred in 1998 due to fires that affected a large portion of the region (CONANP 2007). On the other hand, the extraordinary rainfall occurred at the PNLM in 1860, 1861, 1868, 1893, 1910, 1911, 1917, 1918, 1919, and 1946 are difficult to confirm with weather records other than dendroclimatic reconstructions (Stahle et al. 2020).

A study of the variability of precipitation from the records of the Tonalá meteorological station, located on the coast of Chiapas, from 1961 to 2013, indicates wet years in 1963, 1968, 1973, 1974, 1980, 1981, 1988, 1989, 1995, 1998, 2005, 2006, 2007, and 2013 (Arellano-Monterrosas & Ruiz-Meza 2019); these records generally coincide with above-average precipitation for the PNLM, but were not the most extreme events according to the dendrochronological series.

The general circulation modes that influence interannual climate variability in the PNLM indicate that El Niño is the climate phenomenon with the greatest impact in the region, as shown by the significant frequencies of 4.5, 3.69, and 2.18 found in the total ring-width chronology, corresponding to ENSO at high frequencies reported by Bruun et al. (2017). In the southern part of Mexico, the effect of El Niño shows a contrasting behavior in terms of precipitation, compared to the northern part of the country. El Niño (warm phase) favors higher precipitation levels in winter-spring in northern Mexico, but dry conditions in the south of the country. This behavior is reversed under La Niña (cold phase – Mendez & Magaña 2010), but is similar during intense La Niña events, producing droughts at a national level (Magaña et al. 2003).

The effect of this phenomenon from the climatological perspective has been scarcely documented in this region. A study of the climatic records in the Zanateco river basin, Chiapas, indicates that the volume of rain recorded was related to an El Niño event, as greater or lesser precipitation is related to intense events of this phenomenon, causing variability in evaporation and temperature, although droughts and floods have occurred more frequently from 1997 onwards (Arellano-Monterrosas & Ruiz-Meza 2019).

The influence of other atmospheric circulation models such as AMO and PDO on climate variability in southern Mexico has been little investigated (Stahle et al. 2011). However, studies determining the influence of one of these phenomena, such as AMO, indicates a significant impact on the amount and distribution of precipitation, minimum and maximum temperatures, and

their influence on food production in the coastal regions of Mexico, including Chiapas (Azuz-Adeath et al. 2019). A higher frequency of floods in Chiapas and Tabasco has been recorded during the positive phase of this phenomenon (Valdés-Manzanilla 2016). In the present study, the total ring-width dendrochronological series of *P. oocarpa* showed a significant association with annual AMO indices, although the relationship was weak compared with the influence of ENSO. However, it has been determined that this phenomenon is a key driver of precipitation volumes in the Yucatan Peninsula (Knudsen et al. 2011). Therefore, the influence of this and other circulatory phenomena on the PNLM and other protected natural areas of Chiapas and the south of the country deserves more detailed analyses.

Conclusion

Pinus oocarpa is a dominant species in the conifer forest of the PNLM, and displays a suitable potential for dendroclimatic reconstructions, as indicated by the series inter-correlation value and average mean sensitivity found in the present work. This potential was confirmed by the significant association of the total ring-width series, residual version, and the local, regional, and reconstructed climate databases. The dendrochronological series spanned over 150 years and the total period covered was statistically reliable for climatic reconstruction purposes. It showed a significant response to the cumulative winter-spring precipitation and was negatively correlated with the mean maximum monthly temperature in summer; this suggests that temperature increases over this period may affect the growth of the species and its ecological stability in this conservation area of great ecological and social importance.

The dendrochronology series of *P. oocarpa* showed significant peaks in less than 7 years, corresponding to the frequencies of occurrence of the ENSO phenomenon. In fact, the warm phase of ENSO produced severe droughts, particularly during high-intensity events. The association with the AMO was weaker though significant, and no evidence of the influence of PDO was found.

The understanding and identification of the processes that affect the increasing damage caused by climate change will support the participatory work in the development of management strategies to protect the biodiversity of the PNLM.

Acknowledgments

The leading author acknowledges CONACYT and ECOSUR for funding this research as part of her Ecological and Sustainable Development doctorate studies. Part of the fieldwork and dendrochronological analysis were supported with funds of the project “Dendrochronological Mexican network: hydroclimatic and ecological applications”, FOINS” SEP-CONACYT CB 2016-

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Author Contributions

LPPC: conceived the study and carried out field measurements, samples curation, data processing, bibliographic investigation, methodology and wrote the original draft; JVD: conceived the study, carried out field measurements, made data curation, data processing validation, statistical analysis (dendrochronology), conceived methodology, provided resources, software, supervision, training, and writing review and editing, funding acquisition and wrote the original draft; DART: conceived the study and methodology, supervision and made writing review and editing; BAB: participated in bibliographic investigation, supervision and review, writing-review and editing; GCAG: conceived the study and provided supervision, and writing review and editing.

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