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Resilience of *Pinus durangensis* Martínez in Extreme Drought Periods: Vertical and Horizontal Response of Tree Rings

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Abstract: Extreme drought events reduce the productivity of forest ecosystems. One approach for estimating the effects of drought on forests is by assessing their resilience. The objective of this study was to estimate resilience rates at different heights along the tree stem of *Pinus durangensis* Martínez. The radial growth of 200 cross sections extracted at four heights of tree stems (0.07–0.15, 1.3, 6.3, and 11.0–12.0 m) was analyzed and subsequently transformed into ring-width indices (RWI). These indices were correlated with the Standardized Precipitation-Evapotranspiration Index on a six-month time scale (accumulated drought of six months in the period February–May; $SPEI06_{FM}$). Seven extreme drought events were identified (1890, 1902, 1956, 1974, 1999, 2006, 2011), and radial growth before, during, and after each event was determined. Based on ring-width index values, resistance, recovery, and resilience indices were calculated. The results indicated a significant correlation ($p \leq 0.05$) between annual radial increment and climate indices along the stem (0.56 to 0.80). Climatic sensitivity was higher in the lower part of the stem, with mean sensitivity (MS) and expressed population signal (EPS) values of 0.38 and 0.97, respectively. Resistance index values ranged from 0.44 to 0.76 and were better expressed in higher sections of the stem. Resilience indices changed over time. Regardless of the height of the tree stem, the latest extreme drought events (1999, 2006, and 2011) have led to a lower resilience of trees, indicating that their recovery capacity has decreased. Therefore, forestry practices in the study area may consider managing tree density as a strategy to regulate the stress in competition and to increase the tolerance of trees to drought.

Keywords: tree growth; resistance; recovery; tree-rings; stem analysis; SPEI

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Citation: Cabral-Alemán, C.; Villanueva-Díaz, J.; Quiñonez-Barraza, G.; Gómez-Guerrero, A. Resilience of *Pinus durangensis* Martínez in Extreme Drought Periods: Vertical and Horizontal Response of Tree Rings. *Atmosphere* **2023**, *14*, 43. https://doi.org/10.3390/atmos14010043

Academic Editors: Carlos Rogério Mello, Li Guo, Muxing Liu, Chuan Yuan and Junfang Cui

Received: 6 December 2022
Revised: 21 December 2022
Accepted: 23 December 2022
Published: 26 December 2022

1. Introduction

Forest ecosystems have been seriously affected by frequent climate variations in recent decades [1–4]. The intensity of drought events is one of the main drivers of disturbance, leading to a reduction in tree growth [5], and on occasion to the dieback of trees [6–8]. However, the growth recovery of forest ecosystems after a disturbance event varies with the local climate and species [9]. Another factor that also influences this behavior is forest structure, which regulates resource supply, uptake, and use efficiency [10].

In terms of species, it has been reported that those belonging to the *Pinaceae* family (mainly pines) are less resilient than those belonging to the *Fagaceae* family (mainly oaks) in the face of extreme drought events [9]. This finding may be relevant to the prevailing conditions of the Sierra Madre Occidental (SMO) of Mexico [11], which presents the greatest diversity of associations of pines and oaks worldwide [12]. This places Mexico as a secondary center of diversity of the genus *Pinus*, having about 42% of the species and a high percentage of endemism (>55%) [13]. Among these species, *Pinus durangensis* Martínez is one of the most important due to its distribution area (143,000 km^2), wood quality, commercial value, and for being a key component for the conservation of the SMO's biodiversity [14,15]. However, its extensive logging has reduced the abundance of large trees in many areas, placing it on the International Union for Conservation of Nature's Red List of Threatened Species as Near Threatened [16]. In addition, the susceptibility of *P. durangensis* to extreme drought events has been reflected in radial growth rates [17,18], which may compromise its resilience [19].

In view of concerns about the increasing frequency of extreme drought events in recent years, research efforts have focused on understanding the response of forests to extreme drought [20–24]. Significantly, the analysis of pre- and post-disturbance growth has led to the development of indices, such as quantifiable resilience components [25].

The indices proposed by Lloret et al. [26] have been widely used for quantifying tree resilience. These indices include resistance (*Rt*), defined as the capacity of the tree to sustain growth under disturbing conditions, and recovery (*Rc*), representing the ability of the tree to return to its original condition after disturbance. In forest terms, resilience (*Rs*) refers to the ability of the forest to maintain its original functions under extreme disturbance [27].

Currently, indices for quantifying resilience in forest ecosystems have been addressed using two main approaches: dendrochronology [28–30] and satellite imagery [31,32]. Ring-width chronologies, however, provide information on the growth response to drought at the individual tree level [7] and allow estimating resilience indices on scales ranging from decades to hundreds of years.

Although there is increasing use of resilience indices to analyze the response of trees to extreme drought events around the world, studies involving this approach are scarce in Mexico. In addition, studies based on analyzes of resilience indices through tree rings have been based on radial increases at breast height (1.30 m), which may provide an adequate estimate of radial growth during drought along the stem; however, different results may be obtained in terms of resistance and recovery [33]. In this regard, obtaining information about the response of trees to drought requires the use of growth data at different stem heights in tree species [25].

Based on the above, the objective of this study was to estimate the resilience indices at different stem heights of *P. durangensis* trees in a site in northern Mexico. Particularly, we explored the consistency in resilience indices along the stem of *P. durangensis* trees and whether the resilience of *P. durangensis* has decreased in recent decades. To this end, two main hypotheses were considered: (1) resilience indices estimated for extreme drought events differ along the stem height, and (2) the increase in the frequency and intensity of droughts in recent decades has reduced the resilience of *P. durangensis* to drought. These results contribute to a better understanding of the effects of extreme weather conditions on the growth of *P. durangensis*, a species of great ecological and logging importance in temperate forests in Mexico.

2. Materials and Methods

2.1. Study Area

The sampling site is located in the Sierra Madre Occidental (SMO), northwest of the Durango state (Figure 1a). The site is characterized by uneven-aged vegetation, represented by the genera *Pinus*, *Quercus*, *Juniperus*, *Cupressus*, *Pseudotsuga*, *Arbutus*, and *Alnus* [34]. The sampled trees of *P. durangensis* were obtained in an altitudinal gradient of 2573–2829 m a.s.l., which is its optimal distribution (Figure 1b). The predominant aspect was southwest and had an average slope of 12%. The geographical coordinates are 24°48′16.98″–25°12′38.91″ N and 106°12′37.63″–106°12′25.58″ W (Figure 1c). The main soil types are Leptosol, Cambisol, Luvisol, and Phaeozem [35]. The prevailing climate is cold-temperate, with a mean annual precipitation of 850 mm (Figure 1d) and a mean annual temperature of 10 °C (Figure 1e) [36].

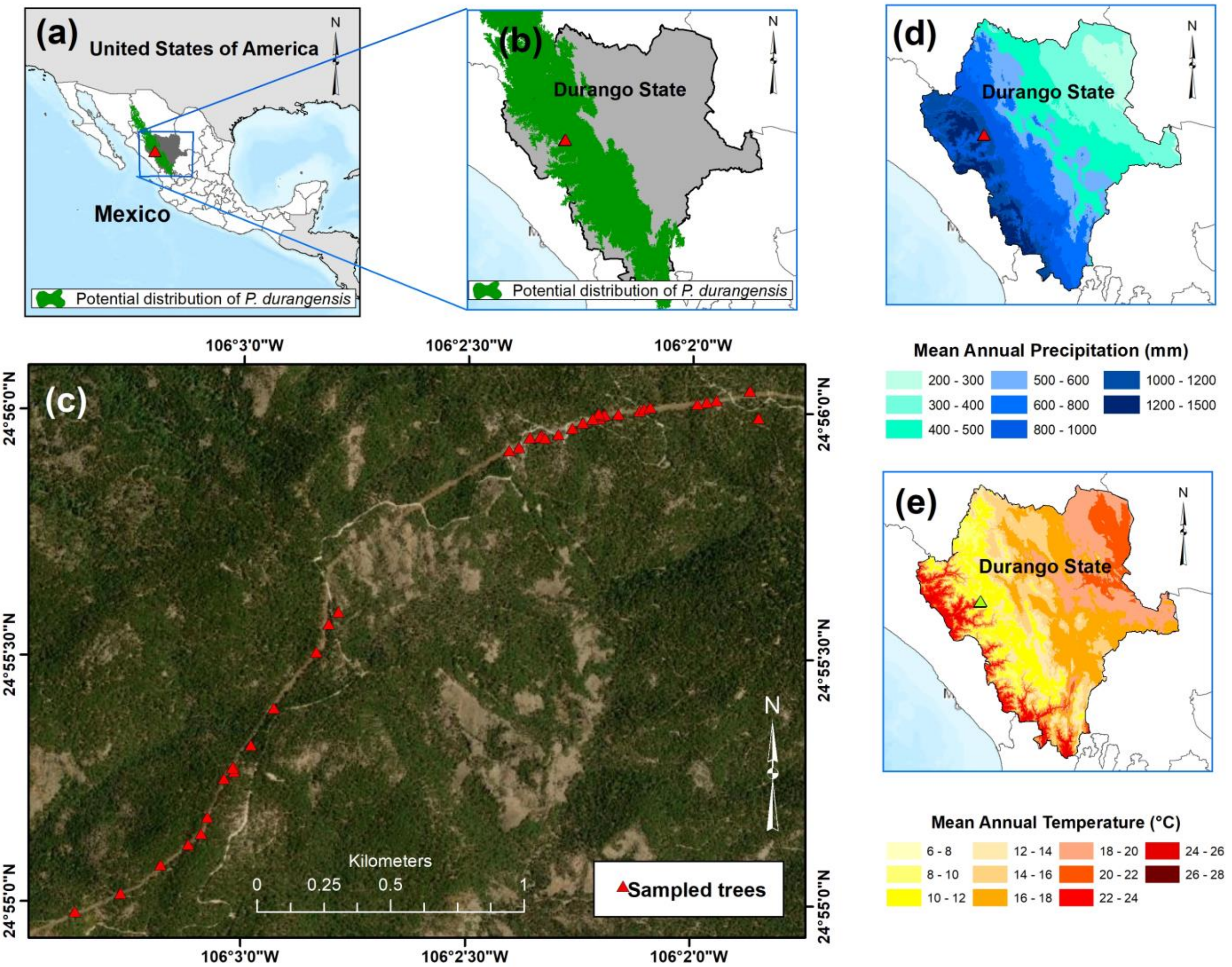

Figure 1. Characteristics of the study area: (**a**) geographic location of the sampling site; (**b**) potential distribution of *P. durangensis* along the Sierra Madre Occidental [37]; (**c**) location of the sampled trees (n = 50); (**d**) mean annual precipitation; and (**e**) mean annual temperature.

2.2. Dendrochronological Information

Fifty *P. durangensis* trees were analyzed, which were selected through directed sampling. Those healthy trees with straight stems and no signs of mechanical damage were chosen. Four cross-sections were extracted from each tree at different heights of the stem. The first section was set between 0.07 m and 0.15 m, the second one at 1.3 m, the third one at 6.3 m, and the last one between 11.0 m and 12.0 m in the height of the stem.

The cross sections were polished and dated based on standard dendrochronological techniques [38]. For each section, the total ring width of two representative radii was measured to an accuracy of 0.001 mm using a Velmex measuring system. Quality in the dating of the ring-width series was checked using COFECHA software [39].

To eliminate biological and geometric trends unrelated to climate, the series were standardized by fitting negative exponential functions. Standardization was carried out using the *dplR* library [40] in R software [41]. This procedure allowed estimating ring-width indices (RWI) for the different heights of the stem. RWI1 is the ring-width index for the first section (0.07 m and 0.15 m), RWI2 for the second section (1.3 m), RWI3 for the third section (6.3 m), and RWI4 for the last section (11.0 to 12.0 m). Those RWI are characterized by being dimensionless, with a mean close to 1.0 and homogeneous variance, but preserving a high portion of the climatic signal [42].

The quality and reliability of chronologies were verified through the mean, standard deviation (SD), mean sensitivity (MS), intercorrelation between series (SI), mean correlation between series (Rbar), first-order autocorrelation (AC1), expressed population signal (EPS) [43,44], and subsample signal strength (SSS) [45]. EPS and SSS are statistics that measure the degree of representativeness of a chronology relative to a theoretical population with an unlimited number of samples. However, the theoretical population is infinitely replicated for EPS, while replication is finite for SSS [46]. In this study, an SSS > 0.85 was used to determine the best replicated period [43].

2.3. Identification of Extreme Droughts

According to Cabral-Alemán et al. [47], the radial growth of *P. durangensis* in the study area is influenced by dominant winter-spring climatic conditions and reported reconstruction of the Standardized Precipitation-Evapotranspiration Index (SPEI) at a 6-month scale (cumulative drought from six months) of February-May ($SPEI06_{FM}$), in the period 1725–2020. In this study, we used the data of $SPEI06_{FM}$ in the period 1880–2020. Based on a statistical criterion, drought events were selected, with extreme droughts defined as the years in which the $SPEI06_{FM}$ values fell out in the lowest fifth percentile [24].

Additionally, the association between the chronologies at different stem heights and the $SPEI06_{FM}$ was calculated with the Pearson correlation analysis using the Minitab 19 software.

2.4. Resilience of Pinus durangensis to Drought

In ecology, the term resilience refers to the ability of natural systems to recover or return to pre-disturbance levels [48]. To optimize the characterization of the response of *P. durangensis* to drought, three resilience components were calculated at different tree stem heights.

The resistance (*Rt*), recovery (*Rc*), and resilience (*Rs*) of a tree to drought events were calculated from the total ring-width index (RWI) based on the formula of Lloret et al. [26], with the *pointRes* library [49] in R software [41]. *Rt* values close to 1.0 denote a high resistance to drought, and *Rc* values less than 1.0 indicate a drop in growth after the drought event. Values of *Rs* equal to or greater than 1.0 indicate the ability to achieve the level of performance before the disturbance. *Rt*, *Rc*, and *Rs* were calculated using Equations (1)–(3). *Rt*, *Rc*, and *Rs* are calculated with Equations (1)–(3).

$$Rt = \frac{G_d}{G_{prev}} \quad (1)$$

$$Rc = \frac{G_{post}}{G_d} \quad (2)$$

$$Rs = \frac{G_{post}}{G_{prev}} \quad (3)$$

where G_d represents radial tree growth (RWI) during drought, G_{prev} is pre-drought growth (mean RWI of four years prior to the drought year), and G_{post} is post-drought growth (mean RWI of four years after the drought year).

The proportion of trees showing high *Rt* and high *Rc* was also calculated. The observed relationship between *Rt* and *Rc* was compared with the hypothetical relationship when full resilience is achieved, and the line of full resilience was calculated using Equation (4) [25].

$$Rc_{h=} \frac{1}{Rt} \quad (4)$$

where Rc_h is recovery assuming a hypothetical full resilience = 1.0

3. Results

3.1. Development of Chronologies

The chronologies estimated for different tree stem heights of *P. durangensis* showed variability in dendrochronology statistics. RWI4 showed peak Rbar and SI values, while the four chronologies greatly exceeded the minimum acceptable EPS value (0.85). RWI1 had the highest MS and AC1 values. SSS values > 0.85 for the four chronologies determined the common period for evaluation, which was 1880–2020 (140 years). Chronology data are shown in Table 1.

Table 1. Dendrochronological statistics for the standard version of the ring-width chronology of *Pinus durangensis* at different tree stem heights.

Chronology	Height (m)		Dendrochronological Statistics							
			Mean	SD	Rbar	EPS	SI	MS	AC1	SSS > 0.85
RWI1	0.07–0.15	1717–2020	0.94	0.35	0.28	0.97	0.60	0.38	0.54	1801–2020
RWI2	1.3	1736–2020	0.95	0.27	0.32	0.98	0.61	0.36	0.36	1797–2020
RWI3	6.3	1797–2020	0.97	0.21	0.33	0.97	0.64	0.32	0.29	1831–2020
RWI4	11.0–12.0	1819–2020	1.00	0.24	0.34	0.97	0.65	0.30	0.46	1880–2020

RWI, ring-width index; SD, standard deviation; Rbar, mean correlation between series; EPS, expressed population signal; SI, series intercorrelation; MS, mean sensitivity; AC1, first-order autocorrelation; SSS, subsample signal strength.

3.2. Relationship between Growth and SPEI

The correlation values between growth data represented by RWI chronologies at different stem heights and drought events represented by $SPEI06_{FM}$ values showed high and significant correlations ($p \leq 0.05$). However, RWI1 and RWI3 were more strongly associated with this index (Table 2).

Table 2. Pearson's correlation analysis between the ring width index (RWI) at different tree stem heights and $SPEI06_{FM}$.

Variable	Pearson's Correlation Coefficient	*p*-Value
RWI1	0.738	0.001
RWI2	0.568	0.001
RWI3	0.803	0.001
RWI4	0.567	0.001

3.3. Identification of Extreme Droughts

The analysis of the variation of $SPEI06_{FM}$ during the period 1880–2020 (140 years) revealed seven years (1890, 1902, 1956, 1974, 1999, 2006, and 2011) with values below the fifth percentile of the distribution. The years resulting from this analysis were classified as extreme drought years. Figure 2a shows the RWI and its graphic relationship with extreme drought events indicated by the $SPEI06_{FM}$ (Figure 2b). The seven years identified as the most severe droughts coincided with variations in radial growth represented by the four chronologies.

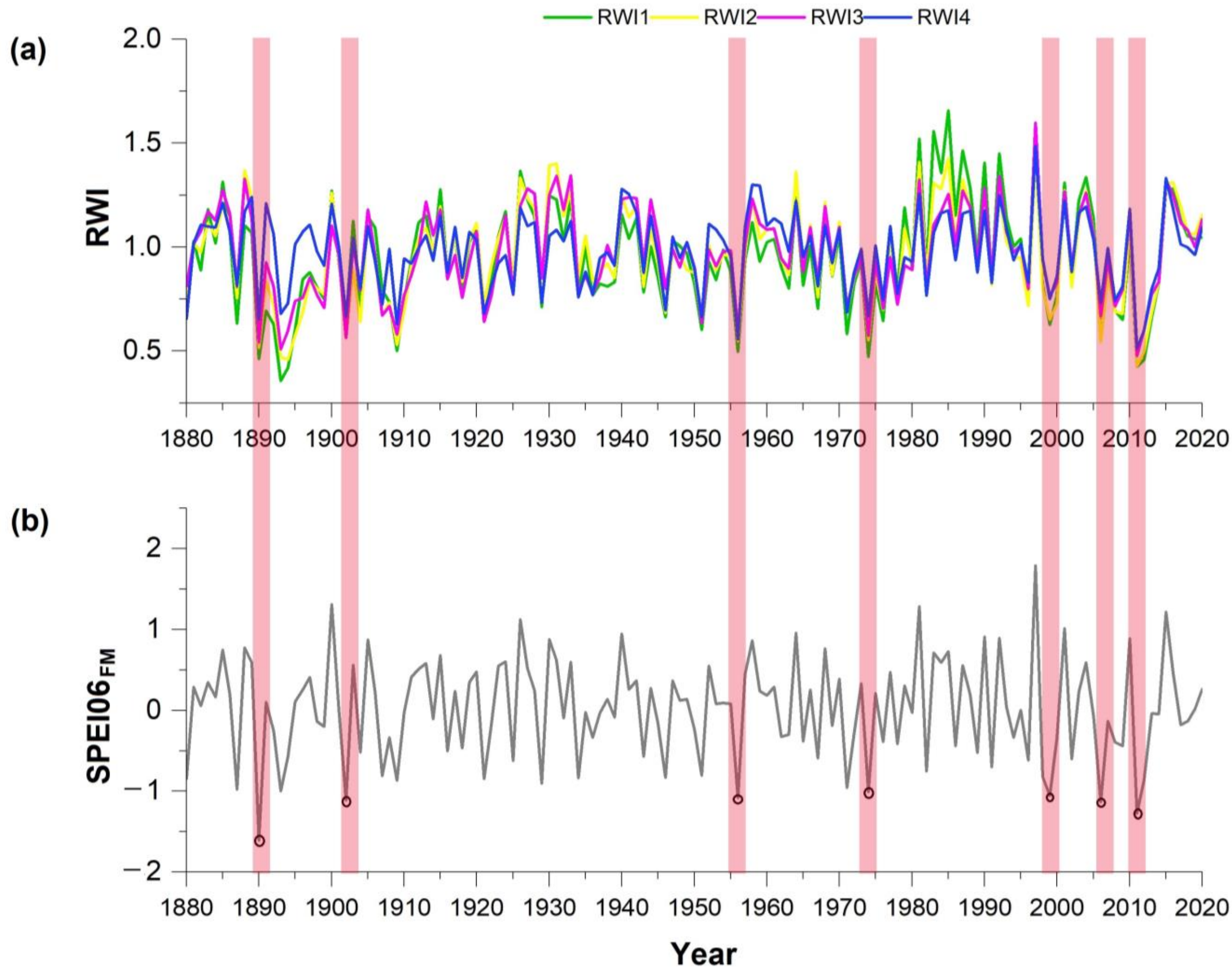

Figure 2. (**a**) Standard version of the ring-width index chronologies at different stem heights in *P. durangensis*, (**b**) SPEI reconstructed for the western region of the state of Durango [47]. Vertical shaded red lines and black circles mark regional extreme drought events.

3.4. Resilience Components

The values of the drought resilience components (*Rt*, *Rc*, and *Rs*) of *P. durangensis* calculated for tree growth (RWI) showed variations between tree stem sections for each extreme drought year. Regarding *Rt*, peak values were found in samples collected for RWI4 (11.0–12.0 m) in the droughts of 1974, 1999, and 2001, with a marked decrease in the 2011 drought. The lowest *Rt* values were observed for RWI2 (1.3 m) and RWI3 (6.3 m) in the 1890 drought (the most severe drought event according to the $SPEI06_{FM}$ reconstruction). Even though an uneven decrease in RWI values was detected for the four stem sections in 1893, corresponding to a low SPEI value, this was not as extreme as the other drought periods and was not selected for further analysis. The *Rc* values increased from 1890 to 1956, then decreased from 1974 to 2006, and increased again in 2011. The four stem sections presented the highest *Rs* values in the 1956 drought, while the lowest values occurred in 1890 (Table 3).

The *Rt* values of the four sections did not reach the reference value (1.0) in any of the drought events, while the *Rc* values were greater than 1.0 in the four sections of all the drought events analyzed. The *Rs* values of the four sections did not reach the reference value (1.0) in the drought events of 1890 and 2006; in 1974, only RWI1 and RWI4 exceeded the value of 1.0; while in 2011, only RWI1 did not reach the value of 1.0 (Figure 3).

Table 3. Mean and standard deviation of resistance, recovery, and resilience indices for each tree stem section of *P. durangensis* in seven selected drought events.

Drought Year		Resistance (*Rt*)				Recovery (*Rc*)				Resilience (*Rs*)			
		RWI1	RWI2	RWI3	RWI4	RWI1	RWI2	RWI3	RWI4	RWI1	RWI2	RWI3	RWI4
1890	Mean	0.51	0.44	0.49	0.64	1.31	1.42	2.34	1.48	0.60	0.57	0.66	0.91
	SD	0.23	0.16	0.13	0.22	0.45	0.67	1.65	0.35	0.27	0.17	0.19	0.29
1902	Mean	0.68	0.59	0.65	0.67	2.28	2.24	2.79	1.79	1.23	1.03	1.19	1.00
	SD	0.32	0.30	0.28	0.29	1.61	1.65	2.63	0.93	0.52	0.41	0.59	0.34
1956	Mean	0.60	0.58	0.64	0.54	2.48	2.59	2.79	2.42	1.39	1.49	1.31	1.20
	SD	0.25	0.22	0.24	0.15	1.40	1.71	4.73	1.29	0.79	1.64	0.49	0.25
1974	Mean	0.56	0.59	0.63	0.75	1.94	1.76	1.61	1.48	1.05	0.96	0.96	1.05
	SD	0.17	0.21	0.23	0.26	0.85	0.75	0.57	0.52	0.43	0.28	0.28	0.27
1999	Mean	0.64	0.68	0.76	0.74	1.98	1.87	1.51	1.50	1.08	1.11	1.03	0.99
	SD	0.30	0.36	0.36	0.33	1.74	1.16	0.82	0.61	0.56	0.64	0.47	0.36
2006	Mean	0.53	0.56	0.64	0.75	1.65	1.62	1.60	1.37	0.79	0.83	0.87	0.98
	SD	0.24	0.20	0.24	0.28	0.70	0.67	1.12	0.51	0.33	0.34	0.29	0.43
2011	Mean	0.51	0.52	0.53	0.56	2.30	2.26	2.12	1.98	1.00	1.02	1.02	1.03
	SD	0.20	0.26	0.19	0.23	1.52	1.15	0.98	0.86	0.41	0.35	0.39	0.35

RWI1, chronology at 0.07–0.15 m stem height; RWI2, chronology at 1.3 m stem height; RWI3, chronology at 6.3 m stem height; RWI4 chronology at 11.0–12.0 m stem height; SD, standard deviation.

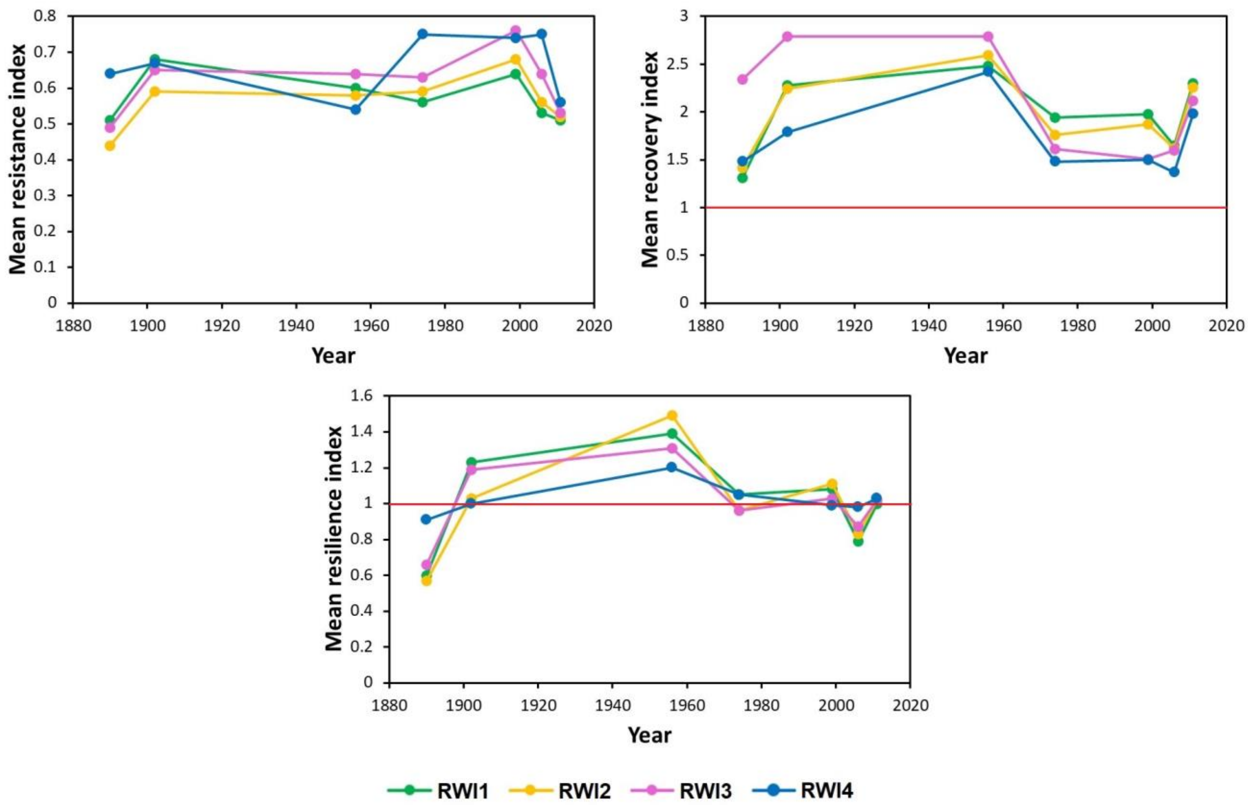

Figure 3. Variation in the resistance, recovery and resilience indices throughout the extreme droughts studied. RWI1 = sampled at 0.07-0.15 m; RWI2 = sampled at 1.3 m; RWI3 = sampled at 1.6 m; RWI4 = sampled at 11.0–12.0 m. The red horizontal lines correspond to mean indices of 1.0 for recovery and resilience, where values over this line imply a full recovery from previous drought conditions, whereas values below 1.0 are indicative that the trees had problems recovering in a four-year period after the dry conditions.

3.5. Line of Full Resilience

The observed values of *Rt* of the 50 trees represent the average for each height in each drought event. The mean values of *Rt* allowed obtaining the values of *Rch*, assuming the line of total resilience (*Rs* = 1.0). During the 1890 drought, the fewest number of trees that reached the line of full resilience occurred. In the 1902 drought, an increase was observed in the proportion of trees that reached the line of full resilience. On the other hand, in the 1956, 1974, and 1999 droughts, RWI1 and RWI2 had the highest number of trees that exceeded the full resilience line. However, in the 2006 drought, a marked drop in tree number was observed, increasing again for the 2011 drought. RWI1 (green dots) generally showed the lowest *Rt* values, which coincided with the highest *Rc* values (Figure 4).

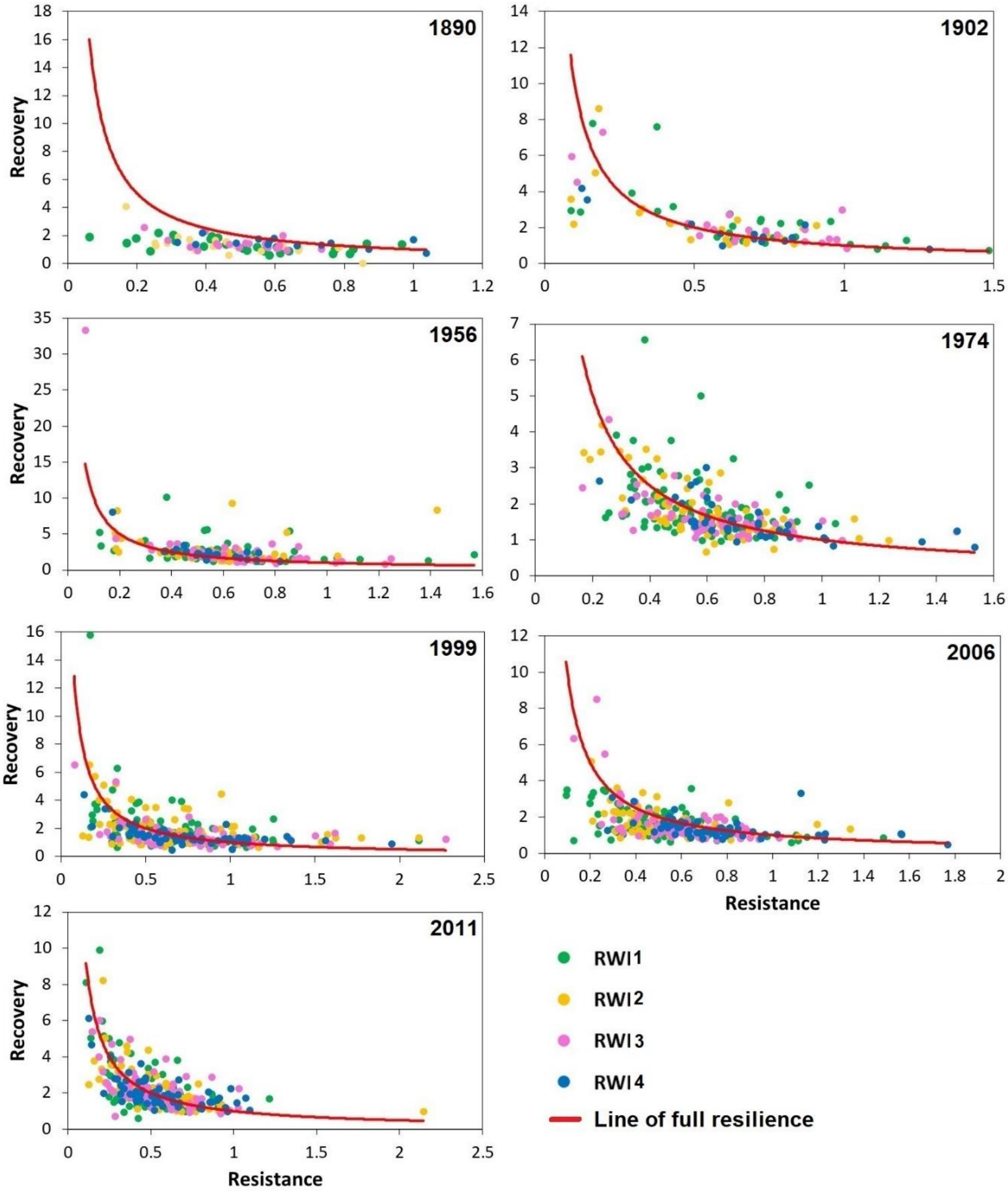

Figure 4. Relationship between the mean *Rt* and *Rc* values observed at different tree stem heights in *P. durangensis* and the hypothetical function representing the line of full resilience at any *Rt* value for each extreme drought year. The dots represent the samples of RWI1, RWI2, RWI3, and RWI4. RWI1 = sampled at 0.07–0.15 m; RWI2 = sampled at 1.3 m; RWI3 = sampled at 1.6 m; RWI4 = sampled at 11–12 m.

3.6. Growth Response of P. durangensis to Drought

A marked reduction in growth was found in all four RWI in the 1890, 2006, and 2011 drought events, while the 1956 drought was associated with a slight increase in growth in all four RWI. In the 1902 drought event, an increase in the growth of RWI1 and RWI3 and a growth decrease in RWI2 and RWI4 was found. In the 1974 drought, there was a slight increase in growth for RWI1, RWI2, and RWI3, respectively (Figure 5).

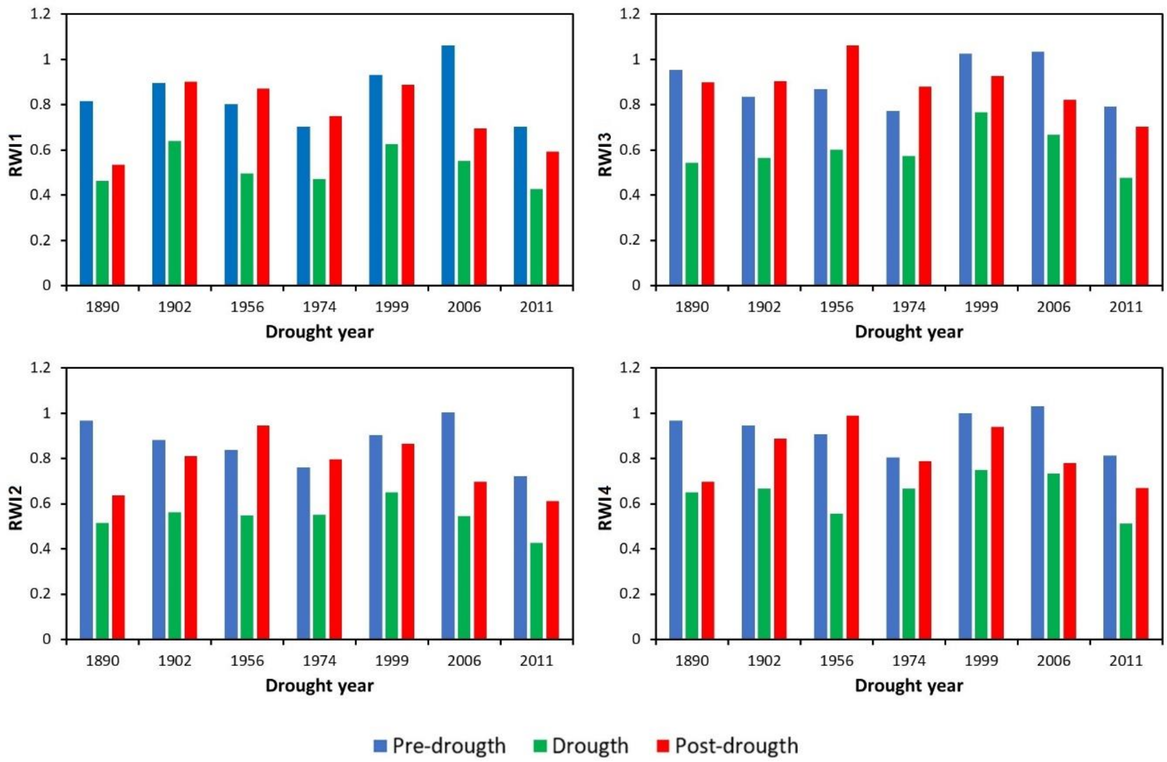

Figure 5. Impacts of seven drought events on forest growth at different stem heights in *P. durangensis* assessed over an average of four years pre-drought, during the drought year, and four years post-drought.

4. Discussion

The results of this study represent the first research of its kind in Mexico. Although these studies generally require destructive sampling and subsequent processing of samples (cross-sections), which is time-consuming and expensive [50,51], they are needed to improve our understanding of the response of tree growth to climate, specifically to extreme droughts. Besides, these elements can be useful for implementing climate change adaptation measures. More importantly, this type of information can be generated more easily in managed forests.

4.1. Dendrochronological Statistics

The dendrochronological statistics indicated high climatic sensitivity in the four series, confirming the potential of this species in the analysis of climatic signals from tree rings. SI values for series collected at different tree stem heights ranged from 0.60 to 0.65 and increased along the stem height. In general, these values suggest an adequate common response between chronologies [52] and are consistent with the report for this species by Villanueva-Diaz et al. [17], who documented an SI of 0.68. In addition, our results coincide with those reported by Martínez-Sifuentes et al. [53], who found an SI of 0.54. MS values ranged from 0.30 to 0.38, reflecting a lower sensitivity as stem height increases. These findings are consistent with data reported from similar studies [54,55].

EPS values for the four series greatly exceeded the minimum acceptable limit of 0.85 and are higher than those reported for coexisting species [56,57]. The assessment period was selected using SSS, considered a more appropriate statistic for determining the common period in chronologies with an intensity threshold of 0.85 [43,46].

4.2. Growth-Climate Relationship along the Stem

Pinus durangensis showed a positive and significant association with $SPEI06_{FM}$ for the four-growth series, with values from 0.56 to 0.80. These results demonstrate the growth response of the species at short time scales, consistent with observations for other conifer species inhabiting temperate zones of northern Mexico [58,59]. The lowest association with $SPEI06_{FM}$ was observed in RWI1 and RWI4, in line with the findings reported by Bouriaud et al. [54], who recorded a lower impact of drought in the upper part of the tree stem. An explanation for the low relationship at this stem height may be related to the proximity of RWI4 to the tree canopy, which is one of the principal carbon (C) sinks. In this portion of the tree, sugars are delivered earlier than in other portions. During drought, C assimilation rates are reduced, and transport is affected, both of which have a greater impact on the lower portion of the stem [33,60].

On the other hand, the highest relationship between growth and climate was observed in the RWI1 and RWI3 sections of the stem, which are considered more sensitive to weather variations than section RWI2, i.e., diameter at breast height (DBH). This indicates that considering only growth at breast height may lead to underestimating the influence of climate on *P. durangensis* growth and, therefore, the impact of climate change on productivity—a process associated with carbon dioxide capture and the adaptation of this species to global warming [61].

4.3. Resilience Indices along the Stem

The seven extreme drought events identified (1890, 1902, 1956, 1974, 1999, 2006, and 2011) coincided with drought periods previously documented for northern Mexico [62]. The response of the four ring-width series in the driest years was similar and consistent with the findings reported for forests of northern Mexico [63].

The result of the analysis of *Rs* indices suggests that the response of *P. durangensis* trees is largely driven by drought intensity, as shown for other species in previous studies [64,65]. The severity of drought events was quantified based on the variability of pre- and post-drought growth, which has been shown to be the main driver of the response of trees to drought [66]. Our results suggest the possibility of a cumulative effect on *P. durangensis Rt* to the 1999, 2006, and 2011 droughts in three (RWI1, RWI2, and RWI3) of the four ring-width series studied. This effect was also evident with a similar variation in *Rc* and *Rs*, with a marked decrease from the 1956 drought in the four-chronology series studied. This may be due to the higher recurrence and intensity of dry periods in northern and central Mexico in recent decades [56,62,67].

The average *Rt* at different stem heights indicated variations from 0.44 to 0.76 (Table 3), indicating that mean radial growth decreased between 56.0% and 24.0% in extreme droughts. This finding is consistent with the one reported by Castrruita-Esparza et al. [68] for *Pseudotsuga menziesii* (Mirb.) Franco, with radial growth reductions of more than 50% under extreme drought. The mean *Rc* by stem height showed values above 1.0 (1.31 to 2.79), indicating that once the drought ended, radial growth increased by 31.0% to 179.0% relative to the growth recorded in the drought year. These results are consistent with those reported for other tree species, such as *Araucaria araucana* (Molina) K. Koch in Argentina [24] and *Pinus ponderosa* Douglas ex C. Lawson in the United States [26]. However, post-drought growth shows a significant decrease relative to pre-drought growth in most cases (Figure 5). This trend may be due to the inherited effects on the long-term post-drought recovery capacity, which may lead to lower productivity as a consequence of reduced radial growth [21].

At the event scale (horizontal averages, Table 3), the 1999 drought resulted in a reduction of up to 76.0% in radial growth. The most remarkable *Rc* response (2.79) occurred after the 1902 drought, while the greatest *Rs* was related to the 1902 and 1956 events

(1.23 and 1.49, respectively) when the trees were young and could recover more rapidly from drought [26,69].

The line of full *Rs* showed that in 1890, most of the trees sampled could not return to the pre-drought growth rates in any series at the different tree stem heights. This event has been reported in different studies as a severe drought associated with La Niña events that lasted for several years [62,70,71]. Therefore, the trees did not recover the pre-drought growth rates. From 1902 to 1974, we recorded an increase in the number of trees reaching pre-drought growth rates, with higher rates in RWI1. However, from 1999 to 2011, the number of individuals achieving pre-drought growth rates decreased again, confirming the significant impact of recurrent droughts in recent decades. The slow growth rate of *P. durangensis*, a species inhabiting temperate zones, can favor *Rt* because slow-growing trees are able to use reserve resources to withstand periods of extreme drought. However, this does not warrant a total post-drought recovery [72–75].

On the other hand, the analysis carried out in this study using tree-ring series at different stem heights supports the hypothesis that the recovery of growth is not homogeneous along the tree stem [25]. The highest values of *Rc* were observed in RWI3 in the first three droughts (1890, 1902, and 1956). However, in the four most recent droughts (1974, 1999, 2006, 2011), RWI1 presented the highest values of *Rc*. In this sense, it has been proposed that under hydric stress, trees may modify their pattern of photosynthate allocation, deriving fewer resources to crown growth and carbon assimilation and a greater allocation to root growth. This strategy captures additional water and, therefore, reduces the growth-limiting effects of this factor [76,77]. However, the practical result of this research indicates that tree-ring sampling at the soil level (0.07–0.15 m) captures the most important information to analyze changes in trees' resilience.

One aspect to be considered in the recovery of tree growth is ecosystem hysteresis since, in the face of climate change effects, forest ecosystems may show a certain lag in recovery (delayed growth response); in some cases, returning to the historical growth rate is no longer possible [11]. It has been observed that the growth recovery of forest ecosystems after a disturbance event varies with local climate and species, with trees of the family *Pinaceae* being the most susceptible and least resilient [9]. Our results showed that it took four years on average for trees to recover the pre-drought growth rate, consistent with Anderegg et al. [9], who reported recovery times between one and four years for chronologies obtained in different parts of the world. On the other hand, it is worth mentioning that after the 1890 drought, it took ten years for trees to reach pre-drought growth levels, a period with no extreme drought events. In contrast, in the case of the 2006 extreme drought event, trees had not fully recovered their pre-2006 growth rate when another extreme drought event occurred in 2011. These findings demonstrate that the high frequency of droughts resulting from climate variations, either naturally or attributed to climate change, may compromise the recovery of *P. durangensis* growth to drought.

4.4. Management Implications

The *Rs* results observed in the present and other studies highlight the need for actions aiming to increase tree drought tolerance. In this regard, forestry has been mentioned as a valuable tool for this purpose [77]. For instance, the growth-climate association has been found to be weaker or decoupled after forest thinning [30]. By increasing the number of resources available for the remaining trees, greater tolerance to extreme weather conditions would be expected [33]. However, some issues related to the benefits of thinning still need to be explained, including how thinning affects climate sensitivity, dependence on growth in the previous year, and the duration of thinning effects [30]. In line with the findings of the present study, further studies should explore the impact of silvicultural activities on drought stress in trees of *P. durangensis* and other species growing in mixed forests in the study area.

Finally, since the *Rs* of trees to extreme drought results from complex interactions acting simultaneously at different spatial and temporal scales [24], future studies should also analyze the resilience of *P. durangensis* along its distribution gradient and consider the factors affecting site quality and the characteristics at the tree level.

5. Conclusions

The growth response to drought differed according to tree stem height in *P. durangensis*. Our results showed that the part of the stem closest to the ground (0.07–0.15 m) exhibited better climate sensitivity. Therefore, the remaining stumps in cutting areas would preserve important dendrochronological information. Drought resistance was generally better in the upper part of the stems. Although recovery was better in the upper parts (RWI3) in the first three drought events, the lower part of the tree stem (RWI1) showed the largest recovery in the last four drought events. In terms of resilience, the latest three drought events have been more frequent and severe, undermining the resilience capacity at different tree stem heights in *P. durangensis*.

The results of the present study refer to *P. durangensis* in the study region. However, they represent a step forward in understanding the behavior of tree growth along the stem, laying the grounds for future studies on this and other tree species in the Sierra Madre Occidental, Mexico.

Author Contributions: Conceptualization, C.C.-A. and J.V.-D.; data curation, C.C.-A.; formal analysis, C.C.-A.; funding acquisition, J.V.-D. and G.Q.-B.; methodology, C.C.-A. and J.V.-D.; resources, J.V.-D. and G.Q.-B.; writing—original draft, C.C.-A.; writing—review and editing, C.C.-A., J.V.-D., G.Q.-B. and A.G.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the project of the Sectoral Research Fund for Education No. 283134/CB 2016-1 “Red dendrocronológica mexicana: aplicaciones hidroclimáticas y ecológicas”. Gerónimo Quiñonez-Barraza obtained financing for field work.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: The first author expresses thanks to CONACYT for her doctoral-awarded scholarship; as well as the project of the Sectoral Research Fund for Education No. 283134/CB 2016-1 “Red dendrocronológica mexicana: aplicaciones hidroclimáticas y ecológicas”. We are thankful to the authorities and technical staff of Ejido San Diego de Tezains for the facilities and support provided in the field sampling.

Conflicts of Interest: The authors declare no conflict of interest.

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