

## Article

# Assessing the Hydric Deficit on Two *Polylepis* Species from the Peruvian Andean Mountains: Xylem Vessel Anatomic Adjusting

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**Abstract:** The impact of drought on vessel architecture and function has been broadly assessed for a variety of tree species in the last decades, but the hydraulic plasticity under temperature increase has scarcely been studied. The effect of drought on tree-ring width and specific hydraulic conductivity depends on relict-tree species resilience to climatic adaptability and its wood anatomical responses to climatic oscillations. We assessed the vessel architecture adaptation of two threatened Peruvian Andean *Polylepis* species (*P. rodolfo-vasquezii* and *P. tarapacana*). We found that historical Peruvian drought years differentially affected *Polylepis* species, where *P. rodolfo-vasquezii* showed vessel anatomical features significantly sensitive to drought events when contrasted with *P. tarapacana*. The drought effect influenced the capacity of *Polylepis* species to adjust the tree-ring width and vessel anatomical traits of their hydraulic system. Our results suggest that drought events influence *Polylepis* species' adaptability and resilience to dry periods and could also restrict them from remaining as a part of the Peruvian Andean puna and mountain ecosystems.

**Keywords:** dendroecology; drought–growth relationships; narrow-ring; vessel traits; wood anatomy



**Citation:** Rodríguez-Ramírez, E.C.; Crispín-DelaCruz, D.B.; Ticse-Otarola, G.; Requena-Rojas, E.J. Assessing the Hydric Deficit on Two *Polylepis* Species from the Peruvian Andean Mountains: Xylem Vessel Anatomic Adjusting. *Forests* **2022**, *13*, 633. <https://doi.org/10.3390/f13050633>

Academic Editors: Marín Pompa-García, Jesús Julio Camarero and Peter Z. Fule

Received: 11 March 2022

Accepted: 15 April 2022

Published: 19 April 2022

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## 1. Introduction

The evergreen *Polylepis* species (“Queñua”) thrives in isolated fragments (1–9 ha) on north-facing steep-slope ravines of the Peruvian Andean montane forests [1]. These endemic species are considered an Oligo-Miocene relict tree species (~25 Ma BP; [2]) and occur in rocky areas with contrasting moisture-retention properties, which affect the hydric deficit of each *Polylepis* species. The long growing season (from November to May) of *Polylepis* species (i.e., *P. rodolfo-vasquezii* L. Valenz. & Villalba) means they are well-adapted to high temperatures (from January to March) and short periods of snowfalls (from late June to July) [3]. Specific climatic fluctuations such as extreme drought events influence their biogeographic distribution [4]. Recently, *Polylepis* taxonomic, genetic, and dendroclimatic studies have increased in the last decades [5–9]; notwithstanding, *Polylepis* wood anatomical adaptation to climatic has not been studied.

Wood features of several *Polylepis* species are characterized as annularly porous or semi-annularly porous aggregated in large vessels at the beginning of the growing season followed by smaller diameter pores in the latewood and band of woody fibers with thicker cell walls [9–11]. Use of wood anatomical traits measured annually across growth-ring sequences is one of the most promising dendroecological tools to study the climatic impact on tree resilience [12]. *Polylepis* species represent a suitable model to assess the adaptive response of vessel traits to hydric deficit, through topographic contrasts in Peruvian Andean

mountains. We studied two relict *Polylepis* species, with contrasting climate variations at sites separated by 860 km from each other.

To explain how *Polylepis* species respond to specific drought events, an increasing number of dendrochronological studies have investigated radial growth of several *Polylepis* species in South America [7,9,13,14]. Notwithstanding, knowledge on xylem vessel as a functional trait to describe tree adaptation strategies to dryness periods, or current and carry-over vessel resilience to drought events, is still scarce for Peruvian Andean *Polylepis* species.

Morphological, physiological, and biochemical responses to drought reduction result in decreases in leaf water potential and sap movement due to alternation of vessel anatomical traits in the plants [15]. During drought events, trees adopt resilience strategies to avoid dry-induced vessel embolism that might decrease hydraulic performance [16]. The vessel hydraulic architecture is more vulnerable to drought-induced cavitation than those with narrower vessels, providing a rough cue to the plant to withstand drought- or frost-induced embolism [17].

In the present study, we tested the hypothesis that specific drought events might influence the vessel architecture adaptation in *Polylepis rodolfo-vasquezii* and *P. tarapacana* Phil. This study is the first of its kind in this region and will help to better understand the wood anatomical plasticity of two relict-endemic Peruvian *Polylepis* species.

Therefore, our aims were to (1) develop accurately dated tree-ring chronologies of two Peruvian *Polylepis* species; (2) compare whether the drought years influenced on RWI; (3) explore how temperature oscillation and wind atmospheric circulation influence the RWI of *P. rodolfo-vasquezii* and *P. tarapacana*; and (4) assess the effect of specific historical drought years on vessel plasticity traits such as vessel diameter, vessel density, hydraulic diameter, and vulnerability index.

## 2. Materials and Methods

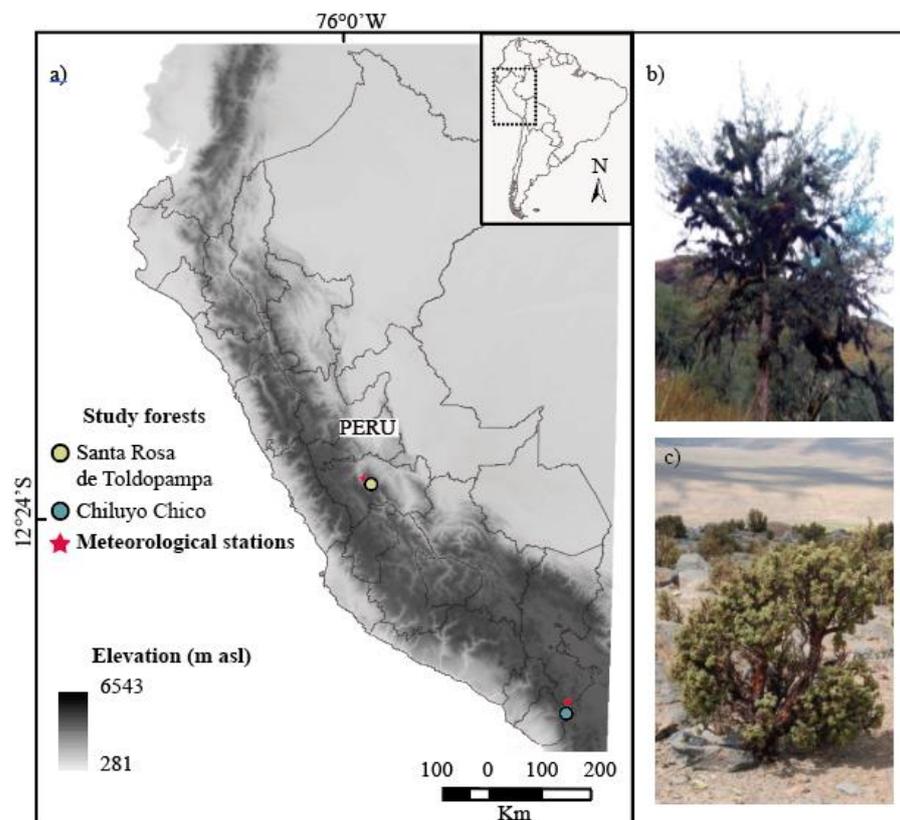
### 2.1. Study Area

Two isolated unprotected fragments of *Polylepis*-dominated trees were selected on the steep-slope ravines on rocky volcanic areas in the southcentral Peruvian Andean montane forests (Figure 1a): (1) Santa Rosa de Toldopampa locality, Pampa Hermosa district, Junín region (*Polylepis rodolfo-vasquezii*; 11°30'19.38" S, 74°53'25.13" W; 3012–3959 m asl) and (2) Chiluyo Chico locality, Tarata district, Tacna region (*P. tarapacana*; 17°24' S, 69°39' W; 4250–4271 m asl). The soil taxonomic classifications at the two sites are Cambisol (Bd) and Alisol district (Al) [18]. *Polylepis* climatic features are described in Table 1.

**Table 1.** *Polylepis* species' climate features.

<i>Polylepis</i> Species	Climate Classification (sensu Peel et al. [18])	Dry Season	Wet Season	Mean Temperature (°C)	Mean Precipitation (mm)
<i>P. rodolfo-vasquezii</i>	Semidry with abundant moisture; C(r)B'	June–August	December–March	8.8	913
<i>P. tarapacana</i>	Semiarid with dry winters; D(i)C'	April–October	December–March	10.9	535

The *Polylepis rodolfo-vasquezii* forest consists of individuals up to  $\leq 10$  m tall and co-occurs with *Gynoxys cusilluyocana* Cuatrec trees and a high abundance of moss on the ground. This forest is growing in a high-humidity microenvironment, protected from sunlight. The understory stratum is mainly composed of *Rubus acanthophyllos* Focke, *R. coriaceus* Poir, *Hesperomeles obtusifolia* (Pers.) Lindl., *Monnina conferta* Ruiz & Pav, *Colletia spinosissima* J.F. Gmel, *Chusquea picta* Pilg., *Acaena ovalifolia* Ruiz & Pavon, *Colletia spinosissima* J.F. Gmel., and *Miconia latifolia* (D. Don) Naudin [19] (Figure 1b).



**Figure 1.** (a) Map showing the location of the *Polylepis* tree-ring sampling in Peruvian Andean montane sites. View of the *Polylepis* species sampled: (b) *P. rodolfo-vasquezii*; and (c) *P. tarapacana*.

The *P. tarapacana* forest consists of individuals ~1–3 m tall; it develops in environments with high sunlight exposure [20]. The mid-canopy ( $\leq 2$  m tall) of the forest is composed mainly of *Adesmia spinosissima* Meyen ex Vogel, *Baccharis tola* Phil., *B. tricuneata* (L. f.) Pers., *Festuca orthophylla* Pilg., *Parastrephia lepidophylla* (Wedd.) Cabrera, and *P. quadrangularis* (Meyen) Cabrera [11] (Figure 1c).

## 2.2. Sampling Tree-Ring Data and Chronology Development

Dendrochronological samples were taken from 10 to 24 *Polylepis* trees at each study forest. We collected two cores of 5 mm increments at breast height (~1.3 m) per tree with a Håglof<sup>®</sup> as well as cross-sections from multi-stemmed trees. Following conventional dendrochronological techniques [21], the samples were codified, glued on wood supports, dried at room temperature, and polished with successive coarse-grit (80, 120, 180, 320, 400, and 600) and fine-grit sandpaper (600, 800, 1000, 1200, and 1500) until optimal visualization of the xylem structure was achieved at 200 magnifications in the transverse plane [22]. All dendrochronological methods were performed following the guidelines and regulations described by Speer [22]. Wood cores and cross-sections were deposited in the Laboratorio de Dendrocronología, Continental University, Huancayo, Peru.

The tree-ring series were dated by assigning calendar year when the tree started growing based on tree rings following the Schulman convention for the Southern Hemisphere [23]. The visual cross-dating was performed using a binocular microscope (OMAX<sup>®</sup>), and the tree-ring widths were measured using a Velmex tree-ring measuring stage (Velmex, Inc., Bloomfield, NY, USA) with 0.001 mm accuracy. The visual cross-dating was verified with the COFECHA software to identify cross-dating errors and false rings [24,25].

To minimize the non-climatic variance related to ontogenetic trends and/or local disturbances [26], we detrended tree rings using a correctly dated series with a negative exponential curve [9,27]. The standard chronology was obtained using the software R v. 4.0.5 using the R-package *dplR* [28] by averaging the individual standardized time series.

The standardized chronology was obtained by averaging the individual residual time series after the removal of the serial autocorrelation from the individual detrended series using autoregressive modeling [29]. We assessed the quality of the chronologies with EPS (expressed population signal) as a measure of the total signal present in the chronology, considering values  $> 0.85$  [30], the mean correlation coefficient among tree-ring series ( $R_{\text{bar}}$ ), and a cubic spline with a 30% response of 15-year periods, to minimize the non-climatic oscillation associated with local climatic variations and to maximize high-frequency climatic evidence [31].

### 2.3. Drought Effect on Tree-Ring Width

To assess the effect of drought on each *Polylepis* chronology, we used data for annual precipitation deviations from two weather stations (from 1966 to 2015): Ricran (for *Polylepis rodolfo-vasquezii*) and Capazo (for *P. tarapacana*) from the Peruvian National Meteorological Service [32,33] to identify years with hydric deficit (Z-score  $< 5$ th percentile). We also explored RWI variation, aiming to identify narrow rings (RWI  $< 5$ th percentile) (from 1960 to 2015) [20]. In order to estimate the drought intensity, the chronologies were compared with the monthly values of the Palmer Drought Severity Index (PDSI; [34]).

### 2.4. Spatial Correlation *Polylepis* Tree-Rings' vs. SST

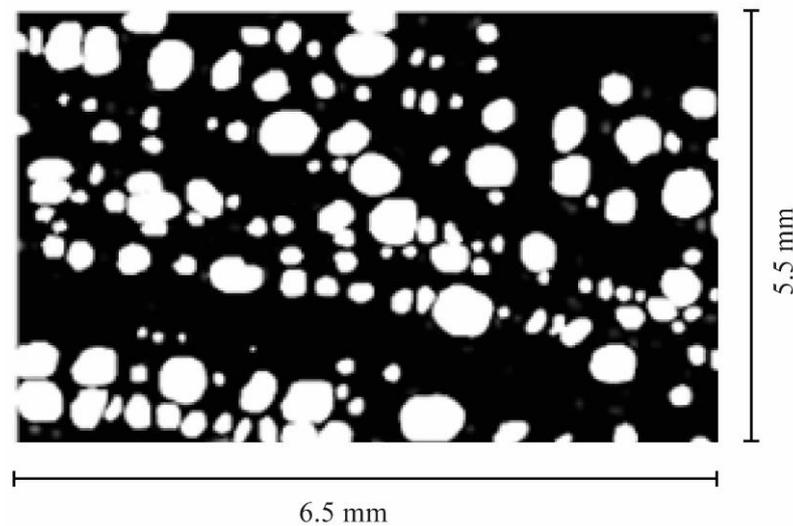
To assess the large-scale climatic effect on tree-ring growth variations, the standardized *Polylepis* chronologies were compared from 1950 to 2015 using correlation analyses (CRU TS 4.0.3 dataset, spatial resolution  $0.5^\circ$  intervals) and linked to spatial fields of climatic variables with ERA5 T2m from KNMI Climate Explorer (<https://climexp.knmi.nl/>), accessed on 21 July 2021. The climatic dataset was partitioned for each *Polylepis* species, and distinct months were used for each species because of the particular drought season variability in the Peruvian Andean puna and montane forests: December–February (*P. rodolfo-vasquezii*) and December–April (*P. tarapacana*), to support specific temperature effects on tree-ring patterns.

Additionally, to detect the effect of heatwaves on the study forests, we used The Monthly/Seasonal Climate Composites dataset (<https://psl.noaa.gov/>; accessed on 10 December 2021 [35]) at pressure levels of 200 hPa (*P. tarapacana*) by the documented linkages between Pacific and Atlantic Ocean SSTs and temperature in the tropical Andes [36] and used the pressure levels of 920 hPa (*P. rodolfo-vasquezii*) to analyze the December–February vector wind trends from 1972 to 2015 over the study sites ( $30^\circ$  S– $15^\circ$  N), possibly associated between tropical North Atlantic and tropical western South America low-level et (LL) circulation [37].

### 2.5. Digitalization of Xylem Vessel Anatomical Traits

For each study forest, we used historical Peruvian drought events (i.e., 1964, 1966, 1969, 1982–1983, 1985, 1987–1988, 1990, 1992, 2004–2005, and 2016 [32,33]) to assess the drought effect on specific vessel traits (vessel diameter, vessel density, hydraulic diameter, and vulnerability index) that could give a better approach to the hydraulic resistance of the diffuse-porous wood of the two *Polylepis* species to drought stress [17]. We randomly selected 10 cores to obtain a digital image of wood cores for the vessel traits measurements. The wood cores were previously prepared using the finest grit (2500, Wetordry™). Wood dust and tylose inside xylem vessels were removed using a hair compressor [38]. Wood samples were stained with black printer ink, and vessels filled with chalk, thus achieving an optimal contrast in the core digital images [39], which allowed the vessel traits measurements (Figure 2). Within each digital image of the wood core, we selected the area occupied by each growth ring between two wood rays ( $\sim 5.5$  mm wide  $\times$  6.5 mm long). The area fluctuated concerning the width of the tree ring (e.g., the widest and narrowest rings were 0.27 mm wide  $\times$  6.1 mm long (ray to ray) and 1.8 mm wide  $\times$  0.9 mm length). Walls of growth rings were delimited using the software Adobe Illustrator CC v. 23.0.5 ([www.adobe.com](http://www.adobe.com); accessed on 2 October 2021 [40]). Each digital image of wood cores was captured using a binocular microscope (OMAX®) with a 10.19 to 40.1  $\mu\text{m}$  field of depth.

Images were taken with a microscope digital camera (AmScope, MU1000) and saved in tiff format with a 10 MP resolution.



**Figure 2.** Processed surface of a cross-sectional digital image of a wood core sample used for vessel measurements. The white circles represent vessels filled with chalk, and the black background shows the core surface stained with black printer ink.

### 2.6. Xylem Vessel Data Analysis

To assess hydric deficit on *Polylepis* species, within each growth ring developed before, during, and after historical Peruvian drought years, the vessels were quantified and measured manually using the software ImageJ.S ([41] <https://ij.imjoy.io/#>; accessed on 2 October 2021) with the VesselJ and Vessel Diameter plugins. The vessel diameter ( $D_V$ ; in  $\mu\text{m}$ ) was determined using the conduit surface area following Scholz et al. [17].

$$D_V = \sqrt{\frac{4A}{\pi}}$$

where  $D_V$  is the xylem diameter and  $A$  is the lumen area. The vessel density ( $VD$ ; number of vessels per  $\text{mm}^2$ ) was quantified separately and measured as the average number of conduits per  $1 \text{ mm}^2$ . The hydraulic diameter ( $D_H$ ; in  $\mu\text{m}$ ) was calculated following the equation

$$D_H = \frac{\sum D_V^5}{\sum D_V^4}$$

where  $D_V$  is the vessel diameter of the vessel  $N$  [39,42]. In addition, we assessed the vulnerability index ( $VI$ ; in  $\mu\text{m} \cdot \text{mm}^{-2}$ ) following the equation [43]

$$VI = \frac{D_V}{VD}$$

where  $D_V$  is the vessel diameter and  $VD$  is the vessel density.  $VI$  values  $\leq 1.0$  suggest a high degree of xeromorphy, while values  $\geq 3.0$  would characterize mesomorphy. We performed Tukey's multiple comparison test to assess whether the vessel traits values show a statistically significant difference between non-drought and drought years for the *Polylepis* species studied. These analyses were performed with the software R using the R-library *ggplot2* and R-package *ggridges* [44].

### 3. Results

#### 3.1. Tree-Ring Chronology

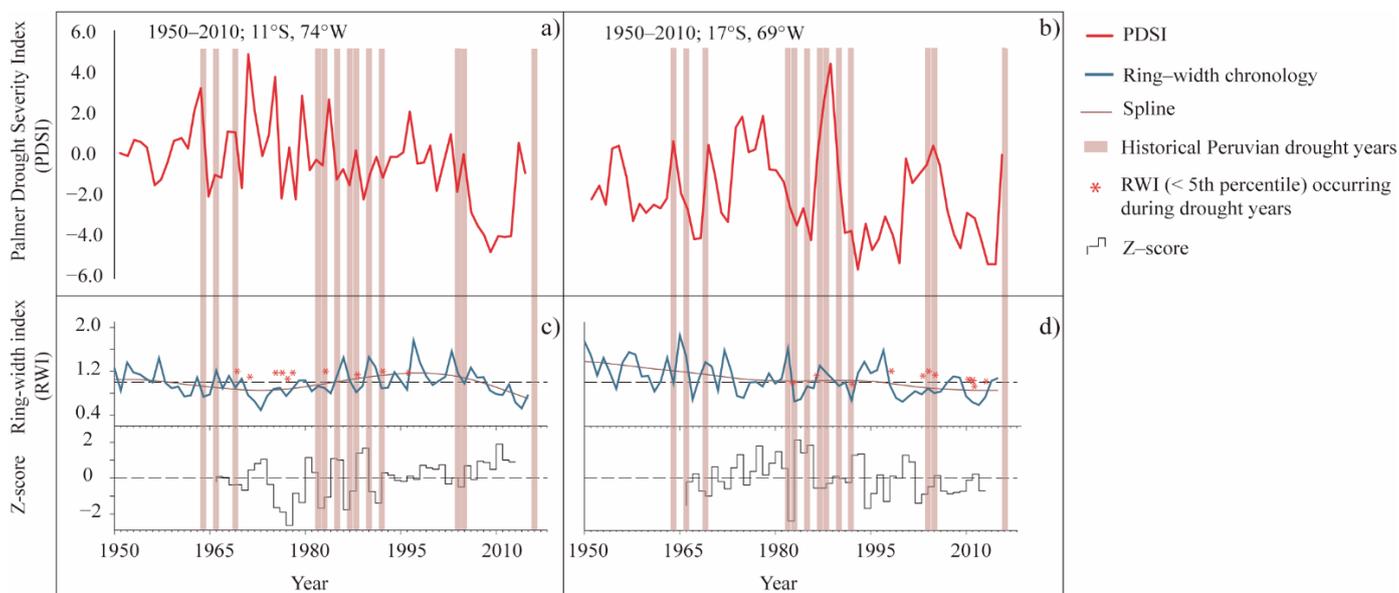
We obtained two independent chronologies, for *Polylepis rodolfo-vasquezii* spanning up to 125 years, and 351 for *P. tarapacana* (Table 2). The inter-series showed high correlations in each *Polylepis* species (*P. rodolfo-vasquezii*,  $r = 0.45$ ; *P. tarapacana*,  $r = 0.63$ ). The EPS and Rbar statistic values showed that the two *Polylepis* chronologies are well replicated (Table 2).

**Table 2.** Statistical features of ring-width index (RWI; a standardized index for annual radial growth) chronologies (Rbar and EPS statistics were calculated from the detrended chronology analysis).

<i>Polylepis</i> Species	Time Spanned	Mean RWI	Samples Live Trees/Stump Cross-Sections	EPS	Rbar
<i>P. rodolfo-vasquezii</i>	1891–2015	1.21	24/6	0.82	0.30
<i>P. tarapacana</i>	1665–2015	0.91	25/6	0.91	0.45

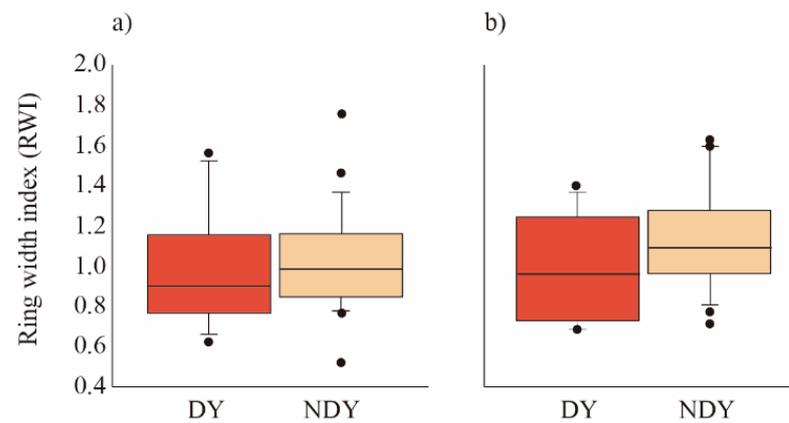
#### 3.2. Drought Effect on RWI

We found a negative RWI effect during specific historical Peruvian drought years (1964, 1966, 1969, 1982–1983, 1985, 1987–1988, 1990, 1992, 2004–2005, and 2016) on the two *Polylepis* species standardized chronologies (Figure 3a,b). Different drought years influenced the RWI of each *Polylepis* species (e.g., *Polylepis rodolfo-vasquezii*: 1964, 1969, 1983, 1988, 1992, and 2005; *P. tarapacana*: 1964, 1983, 1990, 1992, and 2004–2005); these climatic events were detected as narrow ring development (from  $<0.5$  to  $0.7$ ) (Figure 3). The association of narrow ring development with historical Peruvian drought years allowed us to distinguish specific drought events (Z-score  $\leq$  5th percentile) in the ring-width index (RWI): for *Polylepis rodolfo-vasquezii* we detected 10 drought events (1969, 1971, 1975, 1976, 1977, 1978, 1983, 1984, 1988, 1992, 1996; Figure 3c), and 11 for *P. tarapacana* (1967, 1983, 1992, 1998, 2003, 2004, 2005, 2007, 2010, 2011, 2013; Figure 3d).



**Figure 3.** Response of the regional *Polylepis* species chronologies to Palmer Drought Severity Index (PDSI; 1950–2010 period; van der Schrier et al. [34]). (a) *Polylepis rodolfo-vasquezii*; (b) *P. tarapacana*. Standardized tree-ring chronologies for the two *Polylepis* species: (c) *P. rodolfo-vasquezii*; (d) *P. tarapacana*.

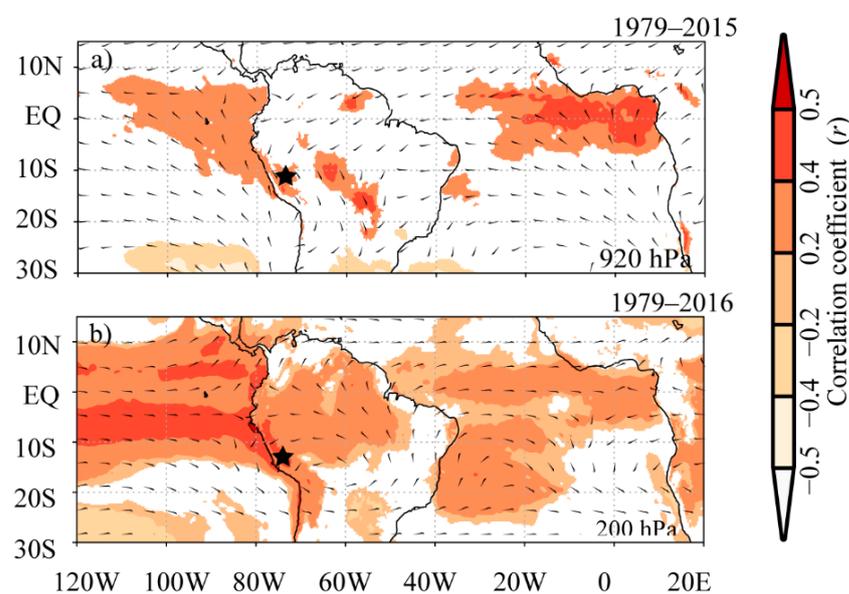
Notwithstanding, tree-ring widths did not differ significantly between DYs and NDYs between *Polylepis* species (Figure 4).



**Figure 4.** Box plots showing the variation ranges of the RWI during DYs and NDYs between *Polylepis* species. The upper and lower limits of the boxes shows the 75th and 25th percentiles, and whiskers represent the 90th and 10th percentiles. Black circles show outliers. The solid line within each box indicates statistically significant differences ( $p < 0.05$ ). (a) *Polylepis rodolfo-vasquezii*; (b) *P. tarapacana*.

### 3.3. Spatial Linking between Tree-Ring Chronologies and High Temperature

Using the standardized tree-ring chronologies for *Polylepis* species, we obtained a regional distribution of the temperature signal detecting a positive correlation with the CRU TS maximum temperature from December to March (Figure 5). The spatial correlation showed that climatic oscillations were controlled by the same mechanisms over western South America for all *Polylepis* species. Likewise, a significant effect of temperature increase and its associated heatwave circulations for the 1972–2015 period ( $p < 0.05$  in Kendall test) were detected. The RWI records are almost identical, with maximum correlations in the study forests and a concentric disposition and residual for Peruvian Andean mountains.

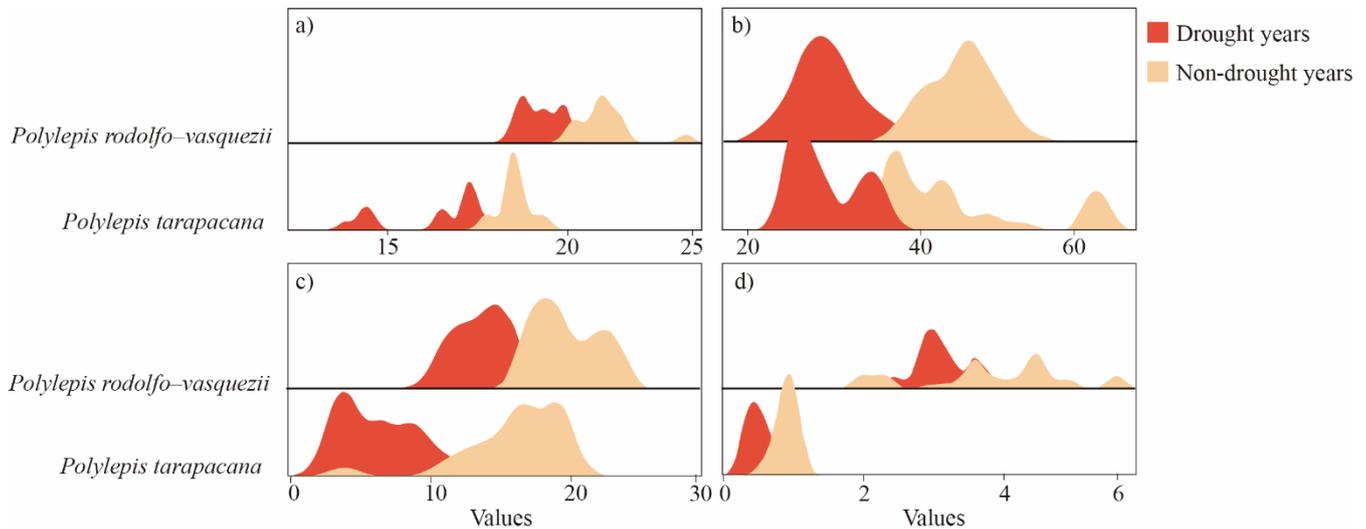


**Figure 5.** Spatial depiction of the correlation between *Polylepis* ring-width indices (RWI) and gridded CRU TS 4.0.3. The climate dataset was split for each *Polylepis* species: December–February (*P. rodolfo-vasquezii*, (a)) and December–April (*P. tarapacana*, (b)) (significance level is 95%) for 1950–2018. The 1972–2015 climatology of horizontal heatwaves wind vectors is from December to February. Only trends at 95% confidence level are shown. Black stars represent each study site for each *Polylepis* species.

### 3.4. Xylem Anatomical Adjusting of *Polylepis* Species to Hydric Deficit

Specific drought events influenced *Polylepis* vessel anatomical traits differently. Each *Polylepis* species showed a unique climatic effect on vessel traits as affected by drought

events, revealed by post-hoc Tukey tests (Figure 6). Our statistical analyses demonstrated that during hydric deficit years, *P. rodolfo-vasquezii* developed low  $Dv$  values varying from 17 to 19.8  $\mu\text{m}$ , while *P. tarapacana* showed values much better adapted to dry conditions, where the  $Dv$  varied from 12.2 to 19.5  $\mu\text{m}$  (Figure 6a).



**Figure 6.** Ridgeline plots showing differences in vessel traits measurements between drought and non-drought years for *Polylepis* species studied: (a) vessel diameter ( $DV$ ;  $\mu\text{m}$ ); (b) hydraulic diameter ( $D_H$ ;  $\mu\text{m}$ ); (c) vessel density ( $V_D$ ; number of vessels per  $\text{mm}^2$ ); and (d) vulnerability index ( $VI$ ;  $\text{mm mm}^{-2}$ ).

Hydraulic diameter ( $D_H$ ) in *P. rodolfo-vasquezii* ranged from 21 to 30  $\mu\text{m}$ , and *P. tarapacana* varied from 24 to 36  $\mu\text{m}$  (Figure 6b). Vessel density ( $VD$ ) was dissimilar between *P. rodolfo-vasquezii* (from 10 to 18) and *P. tarapacana* (from 2 to 12) (Figure 6c). The vulnerability index ( $VI$ ) values during drought years were considerably larger in *P. rodolfo-vasquezii* (from 2.4 to 3.4  $\mu\text{m}$ ) than *P. tarapacana* (from 0.4 to 0.9  $\mu\text{m}$ ) (Figure 6d).

#### 4. Discussion

The availability of long tree-ring series provided us the possibility to explore the year-to-year response (from 1960 to 2015) to climate oscillation for the two *Polylepis* species. Our findings revealed that ring width did not differ significantly between DYs and NDYs between *Polylepis*; however, vessel traits of *Polylepis* species were sensitive to specific drought events. Water shortage during and before the growing season has been shown to decrease secondary growth width, resulting in the development of narrow rings [3,20]. Since diffuse porosity species produce irregularly arranged vessels which are responsible for resilience to climatic year-to-year fluctuations [45], a late-season drought should have greater effects on diffuse porosity species [46]. Even though research on the factors that give rise to variation in legacy effects is still limited, the species specificity to drought [47] and legacy effects highlights the value of our scaling approach. We found that *Polylepis* species show diffuse-porous wood to be more sensitive to drought and have greater legacy effects. For instance, *P. tarapacana* from Altiplano in South America [48] and *Juglans neotropica* Diels and *Cedrela* spp. express reduced tree-ring growth in the Peruvian Andes during specific drought events (from 1960 to 2015) [20,49]. Notwithstanding, what currently demands greater attention is to understand the short- and long-term effects of drought on xylogenesis during the growth season and tree adaptability [48].

Several *Polylepis* species show adaptations to low-temperature and dry physiological environments, thereby allowing them to develop in hotter environments than the global mean for high-elevation tree species [50]. The tree-ring chronologies were correlated with seasonal temperature [51] and heatwave oscillations from the Pacific and Atlantic influencing the climatic signal [37] in *Polylepis* species growth rings. The *Polylepis* chronologies exhibited a

strong correlation with high temperature during a similar period from December to February (*P. rodolfo-vasquezii*), and from December to April (*P. tarapacana*) for 1950–2015 [20]. The climate–growth spatial relationship suggested that the RWI of *Polylepis* was mainly influenced by the drought. Consequently, tree-ring chronologies are a reliable proxy for the effect of high temperature at a local and regional scale. These results are consistent with previous dendroclimatic studies of *Polylepis* species in South America that showed a significant positive association between drought season and growth ring [3,10,20].

Previous studies found that the balance of precipitation and temperature effects can be influenced by specific climatic oscillations [52], but that drought year variations differ locally and can be extremely unpredictable if the increase in temperature is not offset by a regional change in temperature [53]. Notwithstanding, vessel anatomical architecture showed a high adjustment between *Polylepis* species. This result is consistent with the established pattern of vessel trait variability in tree species from climatically different regions and rainfall rates [16]. Under drought-stressed conditions, reduced hydraulic failure and reduced plant water status are minimized by reducing the leaf water potential and sap movement [54]. This is suggested by the subsequent hanging of the stem's anatomical structure, such as reducing the vessel diameter and vessel area. The adaptive capacity of vessels could be influenced directly not only by drought events but also by the abiotic features (e.g., altitude, topography, and environmental moisture), within which are inhabiting *Polylepis* species, indicating the plasticity of each species to climatic events [55]. According to Fonti et al. [56], Kessler et al. [50], and Rodríguez-Ramírez et al. [57], vessel architecture adjustments and micro-climate features among tree species play a key role in ecological adaptation. The observation that when vessel traits adjust (e.g., narrow ring development), hydric deficit and carbon availability are compromised, which can affect subsequent tree adaptability to drought events [58].

Temperature increase and decrease in available water simultaneously drives an increase of evapotranspiration [59] and frequently results in a strong reduction of the vessel diameter ( $V_D$ ) and an increase in their hydraulic diameter ( $D_H$ ) in order to reduce vulnerability to cavitation or embolism [12]. In particular, the vessel traits ( $D_V$ ,  $V_D$ ) of *P. rodolfo-vaquezii* decreased in response to drought events; notwithstanding, the vessel traits ( $D_V$ ,  $D_H$ ,  $V_D$ , and  $VI$ ) of *P. tarapacana* showed a high plasticity to drought periods. The establishment of the *Polylepis* species with a  $VI > 1$  in high Andean mountains indicates that there is high vulnerability to hydric stress effects, implying that *P. rodolfo-vasquezii* ( $VI \sim 3$ ) shows phenological limitations in its growth during long drought periods compared to *P. tarapacana*. Likewise, prolonged droughts as a result of climate change could severely affect this species. Water availability, xylem sap movement, and hydric status of the leaf and the whole plant are maintained by the translocation of sap movement for the plant. The amount of sap translocation xylem vessels and xylem diameter and number play the main role; if the diameter is larger and the density of vessels is higher, then they are more likely to play the main role for xylem sap flow [60]. Vessel trait variations can help to identify those species that are more suitable to hydric deficit conditions [40].

## 5. Conclusions

In this paper, we assessed the drought effect on two Peruvian Andean *Polylepis* species. Thus, our main conclusions may be summarized as follows:

- We highlight that vessel traits prove to have a better climatic signal than growth-ring width in the face of drought events.
- This study exhibits the usefulness of ring-width index and vessel traits as climate-resilience indicators during specific drought conditions.
- Local climatic oscillations can influence vessel anatomical plasticity adaptations.
- Our results suggest that specific climatic events influence each *Polylepis* species' adaptability to drought periods and could also restrict them from remaining as a part of the Peruvian Andean mountain ecosystems.

**Author Contributions:** E.C.R.-R.: Conceptualization, methodology, investigation, data curation, formal analysis, writing—original draft preparation, investigation, supervision, writing—review and editing, project administration. D.B.C.-D.: Methodology, data curation, software, validation, formal analysis, writing—original draft preparation. G.T.-O.: Data curation, validation, writing—review and editing. E.J.R.-R.: Methodology, investigation, data curation, writing—original draft preparation, investigation, supervision, writing—review and editing, resources, project administration. All authors have read and agreed to the published version of the manuscript.

**Funding:** The authors acknowledge the financial support of the CONCYTEC-World Bank Project, through its executing unit, the Fondo Nacional de Desarrollo Científico, Tecnológico y de Innovación Tecnológica (039-2019-FONDECYT-BM-INV Project “El monzón de América del Sur en los Andes Centrales: registros del pasado para anticipar el futuro hidrológico regional”).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Not applicable.

**Acknowledgments:** The authors are very grateful to Juan C. Jiménez-Muñoz for his support in the climate data provided. We thank the constructive suggestions and comments of Laia Andreu Hayles and Carlos Solís-Hay. We are grateful to Gregg Dieringer for his English style review. D.B.C.-D.C. thanks at Fundação de Amparo à Ciência e Tecnologia do Estado de Pernambuco—FACEPE (Process IBPG-1418-5.00/21). E.J.R.-R. was partially supported by project 189-2020 FONDECYT.

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

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