

Drought impact on *Pinus pinea* trees growing in non-native habitats

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Introduction

The mediterranean stone pine (*Pinus pinea* L.) has been increasingly planted both in native and exotic countries given its adaptability, drought tolerance and pine nuts commercial value. The hydric deficit derived from dryer and hotter summers generate negative effects on tree growth, and challenges management. Despite stone pine ability to survive under arid conditions, a reduction in diameter growth has been reported under drought (Natalini *et al.*, 2015), and a shift in the species geographical distribution has been predicted (Akyol *et al.*, 2020).

Several studies have been performed to assess the detrimental climate change effect, but few in stone pine plantations in non-native habitats. In central Chile, where the species is considered as an emergent crop, growth dynamics under drought episodes have been little explored. Thus, this study focuses on the impact of drought on stone pine stem growth by analyzing tree-ring width variations within plantations along a latitudinal gradient

Material and Methods

We sampled and cross-dated 112 trees from four sites along a 600 km latitudinal gradient (Figure 1), measured their tree-ring width series (RWL), and obtained detrended and standardized series of ring width indices (RWIs) (Fritz, 1976). For each series, resilience indices (Rt: resistance, Rc: recovery and Rs: resilience) were calculated (Lloret *et al.*, 2011). Climatic variables (mean, maximum, minimum temperature, and thermal oscillation; potential evapotranspiration (PET), rainfall and hydric index (rainfall – PET)) at seasonal scale (winter, spring, autumn and summer) were correlated to RWIs at each plantation. Multivariate regression was used to explore the responses of chronology of ring width series and resilience indices to seasonal climatic variables during drought years at each site.

Results

Climate influenced the variability of RWIs across all sites, particularly during periods of frequent droughts (Table 1). Regarding the Resistance and Recovery indices, a latitudinal pattern was observed: trees growing in areas with less aridity maintained better growth rates during droughts but exhibited a reduced capacity to recover afterward. Resilience was lowest at the site experiencing more drought episodes, possibly indicating a legacy effect that led to a diminished ability to recover to pre-drought growth rates.

RWIs correlation with seasonal climatic variables were significant for most variables. In all plantations, RWIs showed positive and significant correlations with winter minimum temperature and spring rainfall (Table 2). In the sites where two or more drought years were recorded, RWIs positively correlated to hydric index and rainfall, indicating that tree growth is especially dependent on climate on dry sites.

Stone pine resistance increased with wetter conditions in winter and spring, highlighting the species' sensitivity to climate at the beginning of the growing season (Figure 3). We found that trees with superior RWL were more resistant, but with a lower post-drought recovery; recovery and resilience decreased with site aridity. Trees with inferior RWL were more resilient than trees with superior stem growth.

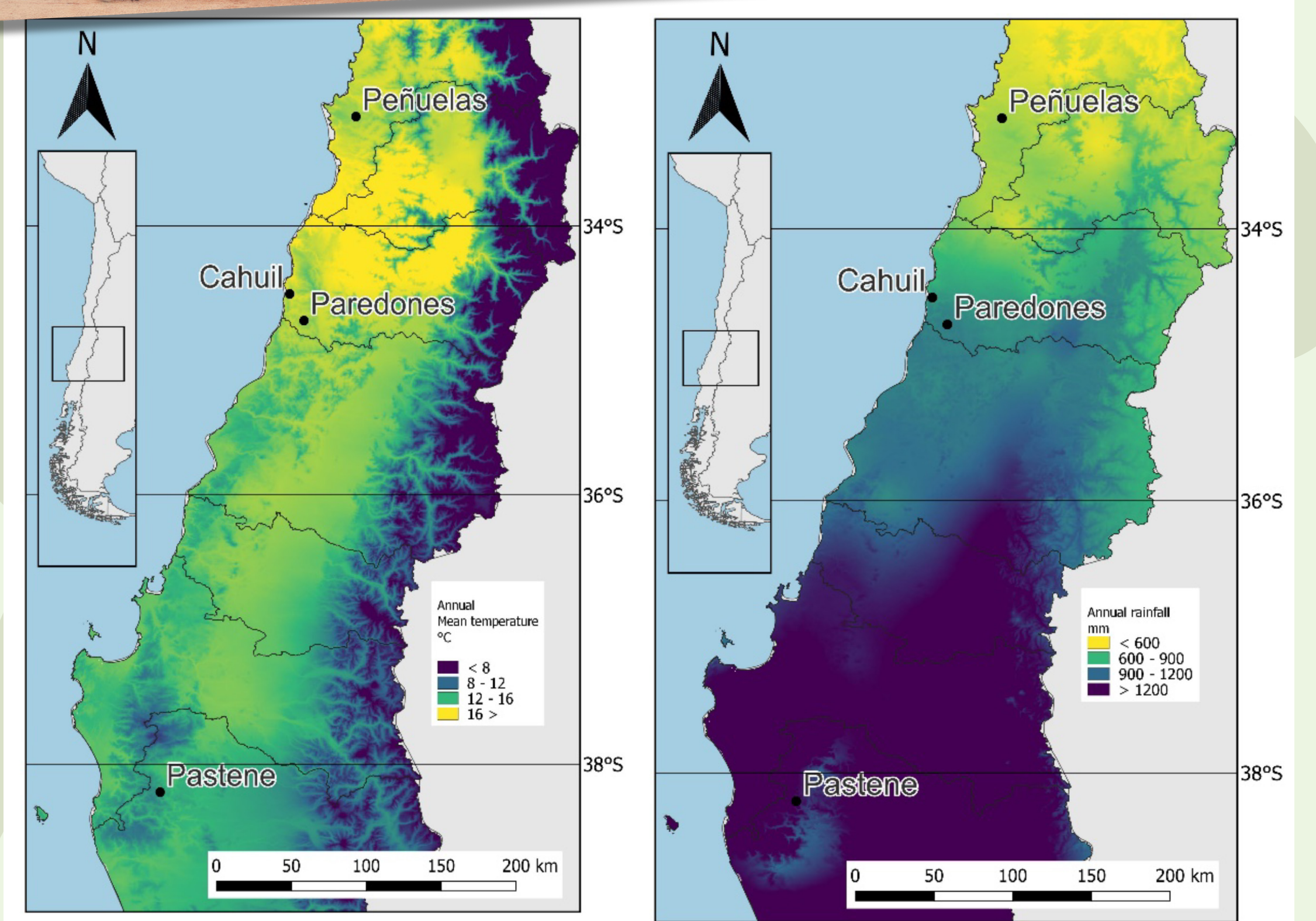


Figure 1. Location of stone pine plantations studied in central Chile, and climate; a) annual mean temperature, and b) annual rainfall.

Table 1

Characterization of stone pine plantations located in central-southern Chile and drought resilience indices (means ± SE).

Variables	Peñuelas	Cahuil	Paredones	Pastene
SD of ring-width index	0.41 ± 0.01	0.41 ± 0.02	0.19 ± 0.01	0.31 ± 0.03
Drought years	2	4	1	1
Resistance index	0.41 ± 0.01	0.42 ± 0.05	0.45 ± 0.00	0.59 ± 0.00
Recovery index	2.42 ± 0.40	2.16 ± 0.62	1.94 ± 0.00	1.77 ± 0.00
Resilience index	0.92 ± 0.12	0.78 ± 0.08	0.93 ± 0.00	1.02 ± 0.00

Table 2

Correlation of ring width index (RWI) and climatic variables

Variable	Peñuelas		Cahuil		Paredones		Pastene	
	Pearson	p-value	Pearson	p-value	Pearson	p-value	Pearson	p-value
AT Wi	0.40	0.0264	0.24	0.1850	0.35	0.0515	0.46	0.0093
Min T Wi	0.47	0.0081	0.37	0.0403	0.37	0.0428	0.50	0.0039
Max T Sp	-0.10	0.5837	-0.47	0.0077	-0.17	0.3606	-0.03	0.8897
TO Wi	-0.47	0.0080	-0.54	0.0016	-0.25	0.1731	-0.28	0.1244
TO Sp	-0.47	0.0078	-0.60	0.0004	-0.52	0.0028	-0.24	0.1952
RF Wi	0.54	0.0016	0.37	0.0397	0.34	0.0625	0.27	0.1373
RF Sp	0.38	0.0335	0.37	0.0403	0.48	0.0060	0.39	0.0284
HI Wi	0.56	0.0010	0.43	0.0169	0.32	0.0755	0.27	0.1494
HI Sp	0.44	0.0127	0.51	0.0035	0.43	0.0147	0.34	0.0620

AT Wi: winter average temperature; Min T Wi: winter minimum temperature; Max T Sp: spring maximum temperature; TO Wi: winter thermal oscillation; TO Sp: spring thermal oscillation; RF Wi: winter rainfall; RF Sp: spring rainfall; HI Wi: winter hydric index; HI Sp: spring hydric index.

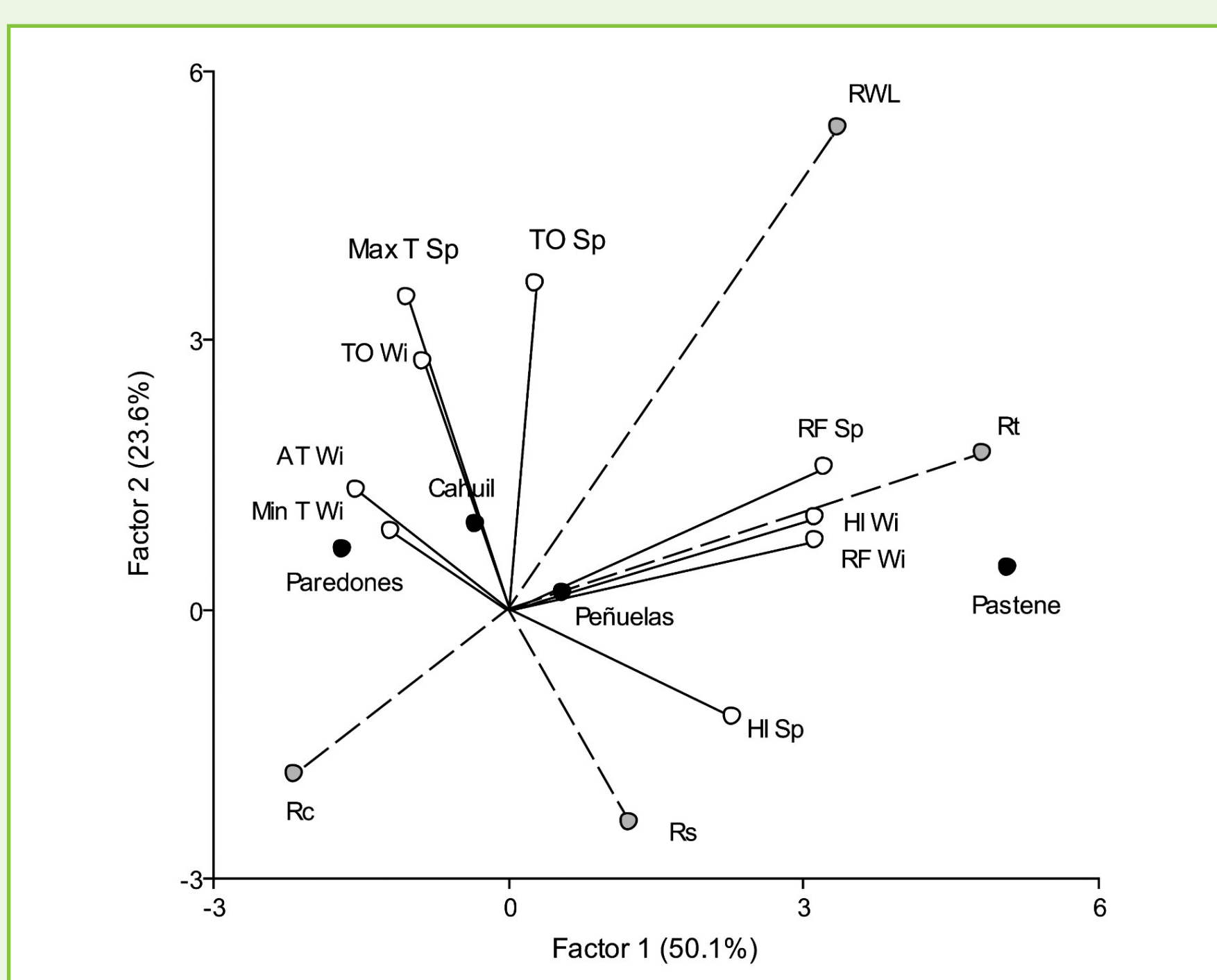


Figure 2. Triplot from PLS regression showing how tree-ring width (RWL) and resilience components (Rs: resilience index, Rt: resistance index, Rc: recovery index) were related to climate variables (TO Wi: winter thermal oscillation; TO Sp: spring thermal oscillation; HI Wi: winter hydric index; HI Sp: spring hydric index; AT Wi: winter average temperature; Min T Wi: winter minimum temperature; Max T Sp: spring maximum temperature; RF Wi: winter rainfall; RF Sp: spring rainfall). Black dots show plantation sites.

Conclusion

Drought reduced stone pine stem growth in plantations established in central-southern Chile, and affected tree resistance, recovery and resilience. At stand level, growth rates and resistance to drought was related to winter and spring climatic conditions. At tree level, trees with higher growth rate were more resistant but showed less capacity to recover than trees with lower growth rate. Stone pine showed drought resilience along a non-native latitudinal gradient, with good adaptation. The high resilience quantified in Chile would indicate that stone pine cropping could be also spread to new areas with hydric limitations.

Keywords: tree radial growth; stone pine; hydric deficit impact; climate change; resilience.