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Climate signals in high elevation tree-rings from the semiarid Andes of north-central Chile: Responses to regional and large-scale variability

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ABSTRACT

In South America, the arid and semiarid subtropical regions through the Atacama Desert and north-central Chile between 19° and 32°S are currently a gap in the tree-ring chronology network. Only a short tree-ring chronology has been published for this vast region and little is known about the suitability of many woody species for tree-ring analysis and dendroclimatology. In this paper we present the first detailed analysis of the climate responses and influences of the El Niño-Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (PDO) on the tree-rings of three species new to dendrochronology and that typically occur at high elevations in the Andes of central and north-central Chile. Three well-replicated tree-ring chronologies of *Kageneckia angustifolia*, *Proustia cuneifolia* and *Fabiana imbricata* are compared with century-long regional records of precipitation and temperature, and with the N3.4 SST and PDO indices in both time and frequency-domains using correlation and wavelet analysis. The radial growth of these species is controlled by winter precipitation and is also positively correlated with temperature during most of the rainy season from April to September (autumn–spring). The regional climate as well as tree growth is strongly modulated by ENSO and ENSO-like conditions in the equatorial Pacific at both interannual and interdecadal timescales. The decadal and interdecadal variability is not correlated with PDO and appears to be related to the Interdecadal Pacific Oscillation (IPO), a Pacific-wide ENSO-like mode of climate variability. Despite their relatively short lifespans, these three new species have a high potential for dendrochronological and dendroclimatic studies in the semiarid region of Chile over the last two centuries.

1. Introduction

In South America, the tree-ring research during the last decades has produced important advances in the understanding of climate variability, ecology and forest management in a range of ecosystems from temperate to tropical regions. Over 200 tree-ring chronologies have been developed in Chile and Argentina, mainly of long-lived or high altitude temperate trees such as *Fitzroya cupressoides*, *Austrocedrus chilensis* and *Nothofagus pumilio* (Villalba, 2000). However, there are important tropical and subtropical gaps in the existing chronology coverage because it is discontinuous and strongly biased to mid-latitudes (~35°–43°S) of the temperate Andes of Chile and Argentina (Luckman and Boninsegna, 2001; Lara et al., 2005). This unbalanced distribution of tree-ring records is mostly due to the wood anatomy complexity and lack of distinct annual tree-rings in tropical species due to absent or weak climate or environmental seasonality (Boninsegna et al., 1989). Nevertheless, the strong rainfall and moisture seasonality in the tropical and subtropical arid regions along the Andes of Argentina, Bolivia, Peru and Chile induces the formation of well-defined annual tree-rings in several of the woody species (Villalba et al., 1985; Roig et al., 2001; Morales et al., 2001; López et al., 2005; Rodríguez et al., 2005). These conditions have enabled the expansion of the tree-ring network into the subtropics. For instance, rainfall-sensitive chronologies of *Juglans australis*, *Cedrela lilloi*, and *Prosopis ferox* extending back over 350 years have been successfully developed in the subtropical montane forests in northwestern Argentina between 22° and 28°S (Villalba et al., 1985; 1987; 1992; 1998; Morales et al., 2004). More recently, a network of well-replicated and century-long moisture-sensitive chronologies from the world's highest forests of *Polylepis tarapacana* has been developed in the semiarid Altiplano plateau of Bolivia, Argentina and Chile at ~4000–5200 m between 16 and 22°S (Argollo et al., 2004; Moya, 2006; Solíz et al., 2009-this issue; Christie et al., 2009-this issue). Chronologies for the related species *Polylepis pepei* have also been developed at lower and more humid elevations of Bolivia at 17°S (Roig et al., 2001). Recent work in Peru has produced short ENSO-sensitive chronologies of *Bursera graveolens* in the dry forests of northwest Peru between 3° and 7°S (Rodríguez et al., 2005) and *Prosopis pallida* along the Peruvian Desert between 5° and 14°S (López et al., 2005; 2006). In addition, other species such as *Eryotheca ruizii* and *Cordia lutea* have proven to be suitable for dendrochronological work in northwestern Peru (Rodríguez et al., 2005).

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Despite these recent developments in subtropical tree-ring research, the arid and semiarid subtropical regions through the Atacama Desert, and north of the Mediterranean region of central Chile from 19° to 32°S, remain as a major gap in the tree-ring chronology coverage along the west coast of South America (Lara et al., 2005; see Fig. 1a). Only a short tree-ring chronology of *Prosopis chilensis* at 29°38′S (López et al., 2006) has been published for the area. This is a key region to examine the influences of ocean/atmosphere processes (e.g. El Niño) on climate and water availability and how these extremely sensitive and threatened ecosystems respond to climate variability and how they will respond to future climate scenarios. This vast region contains woodlands of phreatophytic species mainly of *Prosopis* spp. and shrublands of several drought-resistant shrubs and small trees (Rundel, 1981; Arroyo et al., 1988; Gajardo, 1994; Armesto et al., 2007; Rundel et al., 2007). The potential of these woody species for dendrochronological studies and climatic reconstruction remains unknown and it has been identified as a high research priority (Lara et al., 2005).

In this work we assess the climate signals in the tree-rings of three high-elevation woody species growing in the semiarid Andes of north-central Chile between 29°45′ and 30°59′S, a well-known ENSO-sensitive region at the southern boundary of the Atacama Desert. This semiarid region represents a steep climatic and vegetation transition between the Atacama Desert, north of 28°S, and the Mediterranean-type ecosystems south of ~30°S. These semiarid ecosystems, constrained by a strong climate seasonality imposed by the Mediterranean regime, occupy a narrow band between ~27° and 32°S locally known as *Norte chico* and are highly sensitive to El Niño-Southern Oscillation variability (Holmgren et al., 2001, 2006).

The main goals of this paper are 1) to analyze the responses of the radial growth of three high-elevation species to precipitation and temperature over the entire semiarid region between 27° and 33°S, and 2) to assess the influences of the El Niño-Southern Oscillation (ENSO) and the low frequency ENSO-like mode of the Pacific Decadal Oscillation (PDO) on regional climate and tree growth variability over most of the last century.

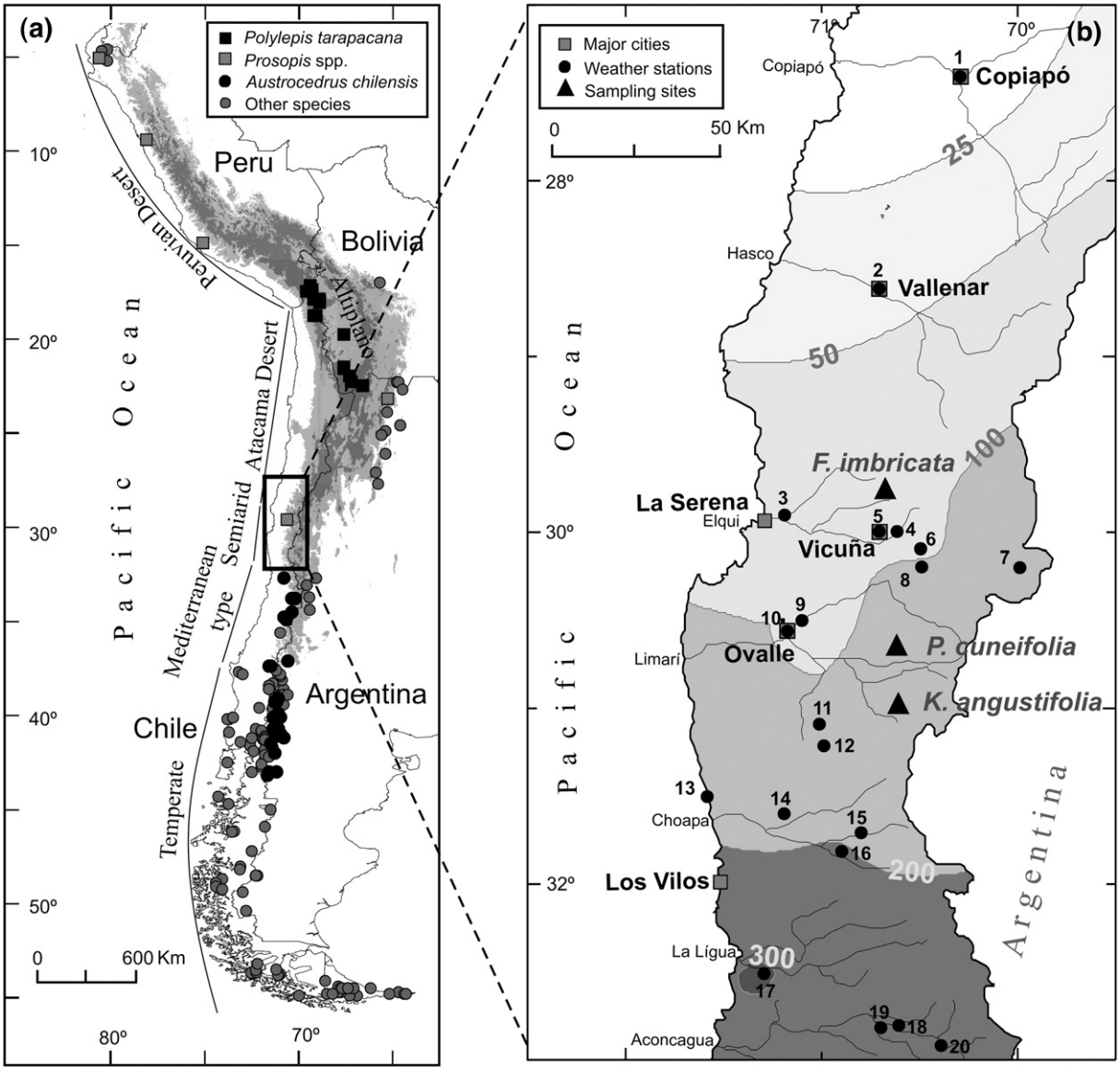

Fig. 1. (a) Map showing the topography and current South American dendrochronological network along the Andes together with the major biogeographic zones through the west coast of South America. The light and dark gray shading indicates elevations above 2000 and 4000 m, respectively. The chronology locations were obtained from the International Tree-Ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html) and a literature survey. (b) North-to-south precipitation gradient and location of the tree-ring sites and meteorological stations (see codes in Table 2) in the semiarid region of north-central Chile. The isohyets (mm year^{-1}) are based on the common period 1964–1990 and were calculated using the kriging interpolation method. The main cities and rivers along the region are also indicated.