Palaeogeography, Palaeoclimatology, Palaeoecology 461 (2016) 44–54

Contents lists available at ScienceDirect

Palaeogeography, Palaeoclimatology, Palaeoecology

journal homepage: www.elsevier.com/locate/palaeo

Late Holocene environmental changes as recorded in the sediments of high Andean Laguna Chepical, Central Chile (32°S; 3050 m a.s.l.)

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ARTICLE INFO

Article history:
Received 9 December 2015
Received in revised form 25 July 2016
Accepted 1 August 2016
Available online 4 August 2016

Keywords:
Late Holocene
ENSO
Pollen
Diatom
Andes
Climate change

ABSTRACT

We present a reconstruction of environmental changes from sediments of high-altitude Laguna Chepical in the subtropical Andes of Central Chile (32°16′S; 70°30′W, 3050 m a.s.l.) for the past 3100 years. Based on subfossil pollen, microscopic charcoal and diatoms, we inferred changes in moisture (related to precipitation) and ice-cover/ice-free season (related to summer temperature) at decadal to millennial scales. Sustained wetter and colder summer temperatures than today prevailed between 1100 BC and ca. AD 1. Afterward, decreasing pollen accumulation rates and increased fire activity suggest drier conditions and possibly enhanced seasonality and/or inter-annual climate variability. Frequent changes between cold and warm summers were observed, particularly for the last 1000 years. About AD 1250 (during the Medieval Climate Anomaly), wet years and early break up of ice-cover occurred in central Chile, which is today typical for El Niño-like mean conditions. Conversely, and with the exception of a few wet pulses, a generally dry period with extended ice-cover (cool summers) was observed between AD 1400 and AD 1850 (Little Ice Age). This can be interpreted as a trend toward more La Niña-like mean conditions. Recent climate change and human disturbances during the last 100 years have prompted changes in diatom and plant communities that are unprecedented in the late Holocene. First, planktonic diatoms increased as a result of hydraulic interventions in the lake during the late 19th century, and secondly, the Andean vegetation shifted upward as result of recent warming, and the frequency of arboreal taxa was significantly reduced. At the same time peaks of fire activity were observed.

1. Introduction

Mountain ecosystems are characterized by steep gradients in precipitation, temperature and other environmental variables. Thus, plant communities in mountain habitats are potentially very vulnerable to climatic changes (Arroyo et al., 1993; Beniston, 2003; Diaz et al., 2003; Fagre et al., 2003). The Andean Cordillera and the foothills of Central Chile (30°–36°S) are among those areas in the world that experience particularly strong desertification as a consequence of ongoing climatic change (Carrasco et al., 2005; Fuenzalida et al., 2006; Rosenblüth et al., 1997; Trenberth et al., 2007). Studies of global warming scenarios for the subtropical Andes project a substantial decline of precipitation (−30%) for the 21st century and an increase in temperature (+3–4 °C). Moreover, a concomitant decline in the snowpack and changes in the snowmelt and stream flow regimes are expected (Carrasco et al., 2005; Fuenzalida et al., 2006; Vicuña et al., 2011), which will negatively impact water storage for the surrounding foothills during the dry summer season. Andean biota will be affected and may be displaced because of a reduction of habitat (Arroyo et al., 1993; Pliscoff et al., 2012). At the same time, socioeconomic activities (e.g. hydropower generation, agriculture, domestic water consumption) will also be impacted by the decreased water availability. This is a serious problem, because the demand for water is high and rapidly increasing in this area: indeed, this is the area with the highest population of Chile (11.5 million; 65% of population) and with water demand for boosting industrial agriculture and mining (AGRIMED, 2008; CEPAL, 2012). This makes central

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http://dx.doi.org/10.1016/j.palaeo.2016.08.003
0031-0182/

Chile, and in particular the semiarid Andes, extremely vulnerable to climate change. The knowledge of the natural climatic system dynamics provides a baseline against which future scenarios can be compared.

Central Chile also is a key area to study the interaction between the Southern Westerly Wind Belt (SWWB) and the Southeast Pacific Subtropical Anticyclone (SEPSA) (Jenny et al., 2002). Moreover, extreme climatic variability in this area is associated with large-scale ocean-atmosphere phenomena, such as the El Niño Southern Oscillation (ENSO) and the Pacific Decadal Oscillation (Montecinos and Aceituno, 2003; Quintana and Aceituno, 2012). The warm phase of the Southern Oscillation (El Niño) is typically associated with a weakened SEPSA and enhanced blocking in the Amundsen–Bellingshausen seas in Antarctica (southeast Pacific), which produces increased storminess, above average precipitation and snowpack formation in central Chile, whereas generally opposite conditions occur during La Niña cold phases (Masiokas et al., 2006; Montecinos and Aceituno, 2003; Rutllant and Fuenzalida, 1991). Particularly because SEPSA is modulated by the Southern Oscillation, there is a strongly negative correlation between the Southern Oscillation Index and winter rainfall over the region (Fig. 1a). During negative SOI phases, high rainfall is expected and vice versa (Quintana and Aceituno, 2012). Surface air temperatures are generally warmer during warm ENSO phases, particularly in fall and winter (Garreaud, 2009).

Continuous paleoclimate archives from this area contain information that can be used for comprehensive regional, continental and hemispherical assessments of climate variability during the late Holocene (Neukom et al., 2010, 2011, 2014; PAGES-2k-Consortium, 2013). In a recent study, de Jong et al. (2013) presented a high-resolution (subdecadal) record of warm season temperature (November to February) from Laguna Chepical, which provided, in combination with information from nearby low elevation (350 m a.s.l.) Laguna Aculeo (von Gunten et al., 2009), insight into the similarities and dissimilarities of temperature variability at high and low elevation sites. The main results of NDJF temperatures from L. Chepical record show, cooler summers, except for the 18th century and especially around AD 1940–1970, when the warmest temperatures are recorded for the last 3000 years.

Here we present the results of pollen and diatom analyses from Laguna Chepical. In this investigation we explore whether biological proxies contain information about past precipitation and moisture regimes to complement the existing reconstructions of summer temperature. Moreover, we were interested in whether and how anthropogenic activities may have influenced this remote high Andean site.

2. Study area

Laguna Chepical (32°16′S; 70°30′W, 3050 m a.s.l.) is a high Andean, oligotrophic endorheic cold-monomictic freshwater lake located on the western slope of the Andes in Central Chile (Fig. 1b). The geologic bedrock of the lake catchment is composed of volcanic basaltic, andesitic and dacitic rocks of Middle to Late Miocene age (Munizaga and Vicente, 1982). According to de Jong et al. (2013), the lake sediments consist of diatomaceous organic silt (C_{org} 8–20%). The top part of the

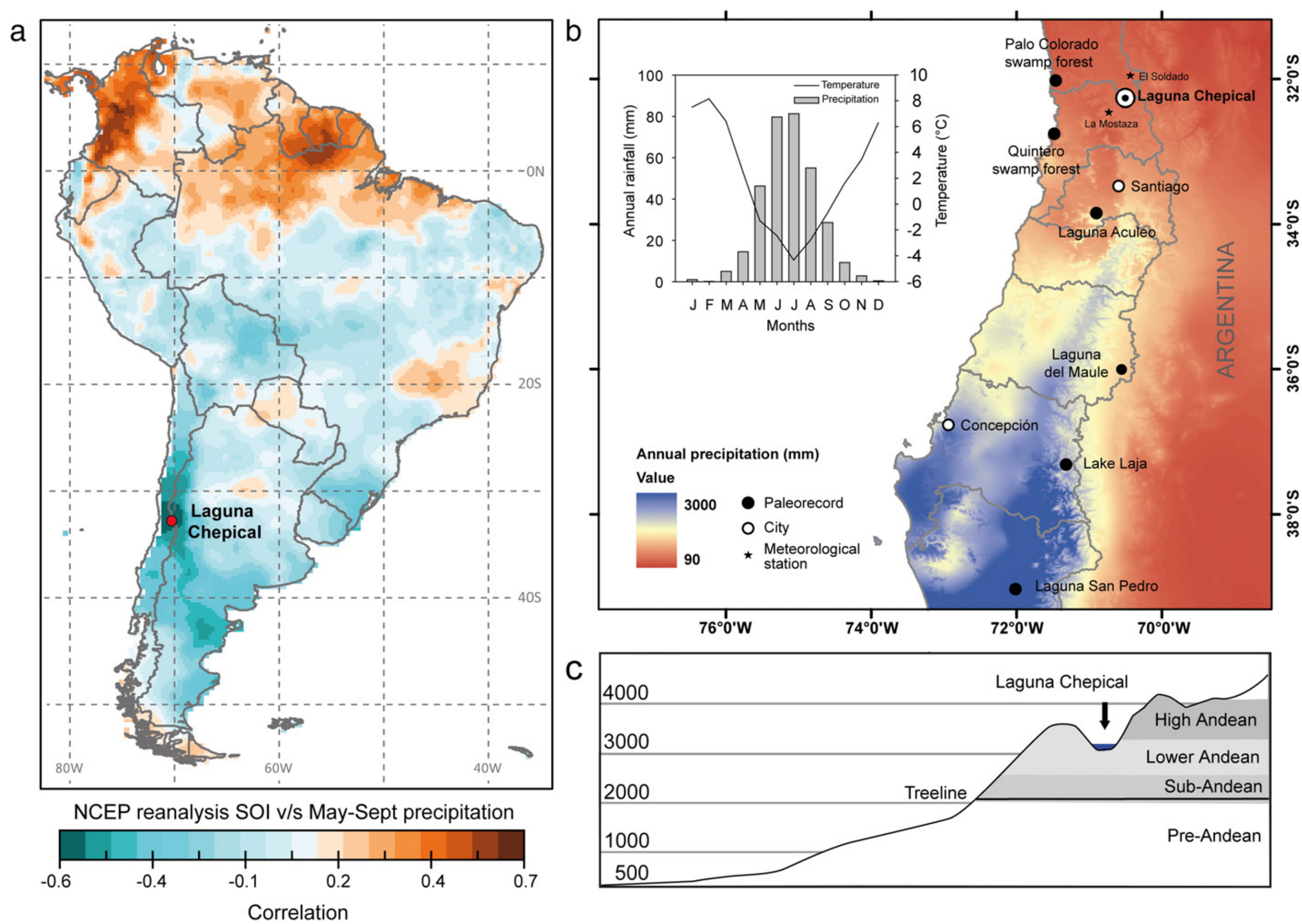

Fig. 1. a) Map of South America showing the spatial correlation between austral winter rainfall and the Southern Oscillation Index (NCEP reanalysis, NOAA) and the location of the study area. Note the strong negative correlation in the region of Laguna Chepical. b) Details of the study area showing Laguna Chepical and the nearest paleorecords discussed in the text, and the gradient of annual precipitation. The ombrothermic graph shows the annual distribution of temperature (El Soldado meteorological station, 32°S, 70°19 W, 3290 m a.s.l.) and precipitation (La Mostaza meteorological station, 32°25′S, 70°40′W, 1200 m a.s.l.). c) Altitudinal vegetation belts of the study area.