Research Paper

Disentangling the Medieval Climatic Anomaly in Patagonia and its impact on human societies

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Abstract

This paper revises paleoenvironmental data from Patagonia (southern South America) to discuss the occurrence, characteristics, and human impact of the Medieval Climatic Anomaly (MCA). The analysis of continuous paleoenvironmental archives with multidecadal-to-centennial resolution is based on a quality assessment regarding data interpretation, chronological control, and time range adequacy within the MCA lapse. After applying this three-stepped quality filters on the total dataset ($N=48$), 18 cases can accurately be ascribed to the MCA. Except for two sites indicating wetter conditions, these records show dry and/or warm conditions between ca. 750 and 1350 CE (core period at ca. 800–1200 CE). Even though MCA records come mostly from forests and forest-steppe ecotones, all previous archeological hypotheses about the MCA effects on past hunter-gatherers were proposed for the steppes, particularly in southern sectors, thus requiring an assessment of the source of the signal, their synchronicity and causality between human-environmental processes. In the southern steppe, paleoenvironmental records partially overlapping with the MCA time window actually show a predominance of wet conditions between 47° and 50° S, whereas a generalized aridity is recorded in southern tip of the continental Patagonia between 51° and 52° S. Thus, a complex scenario of landscape fragmentation can be supported in the southern steppes during the MCA, produced not only by enhanced aridity in dry environments, but also because of the presence of wet and more resilient areas. This landscape heterogeneity must be considered to deepen the understanding of behavioral changes contemporaneous to the MCA. However, a scenario of demographic growth suggested around 1000 CE for the entire Patagonia could have promoted human changes similar to those expected for the MCA. Finally, no-archeological discussions linked to the MCA were developed for forest regions, despite their robust paleoenvironmental records, implying that changes in proxy data might not have necessarily involved important environmental changes.

Keywords

ecosystems resilience, hunter-gatherers, landscape fragmentation, medieval climatic anomaly, paleoenvironmental records, Patagonia, quality assessment

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Introduction

The Medieval Climatic Anomaly (MCA) comprises a significant climatic event of the last millennium, along with the subsequent Little Ice Age and the 20th century warming acceleration (e.g. Neukom et al., 2014). Paleoenvironmental and historical data recovered mainly from the Northern Hemisphere define the MCA as a centennial thermal anomaly that occurred between ca. 900 and 1300 CE (Diaz et al., 2011; Mann et al., 2009), causing warmer surface temperatures and drier conditions – compared with the pre-1970 modern average – in several parts of the world (e.g. Graham et al., 2011, and references therein). The most accepted forcing mechanisms postulated to explain this ubiquitous – though climatically and temporally heterogeneous phenomenon – have been the amplification of moderate changes in external forcing's (i.e. solar activity and volcanism) by the internal ocean-atmosphere system (e.g. Ahmed et al., 2015; Bradley et al., 2003; Cobb et al., 2003; Diaz et al., 2011; Graham et al., 2011; Gray et al., 2010; Mann et al., 2009; Neukom et al., 2014; Stine, 1994, and references therein). Instrumental, historical, paleoenvironmental, and archeological records have extensively highlighted the impact of the MCA over the economical, geopolitical, social and technological aspects of human populations in different parts of the world (e.g. Arnold et al., 2021; Dewar and Marsh, 2019; Jackson et al., 2018; Jazwa et al., 2019; Jerardino et al., 2018; Jones and Schwitalla, 2008; Jones et al., 1999;

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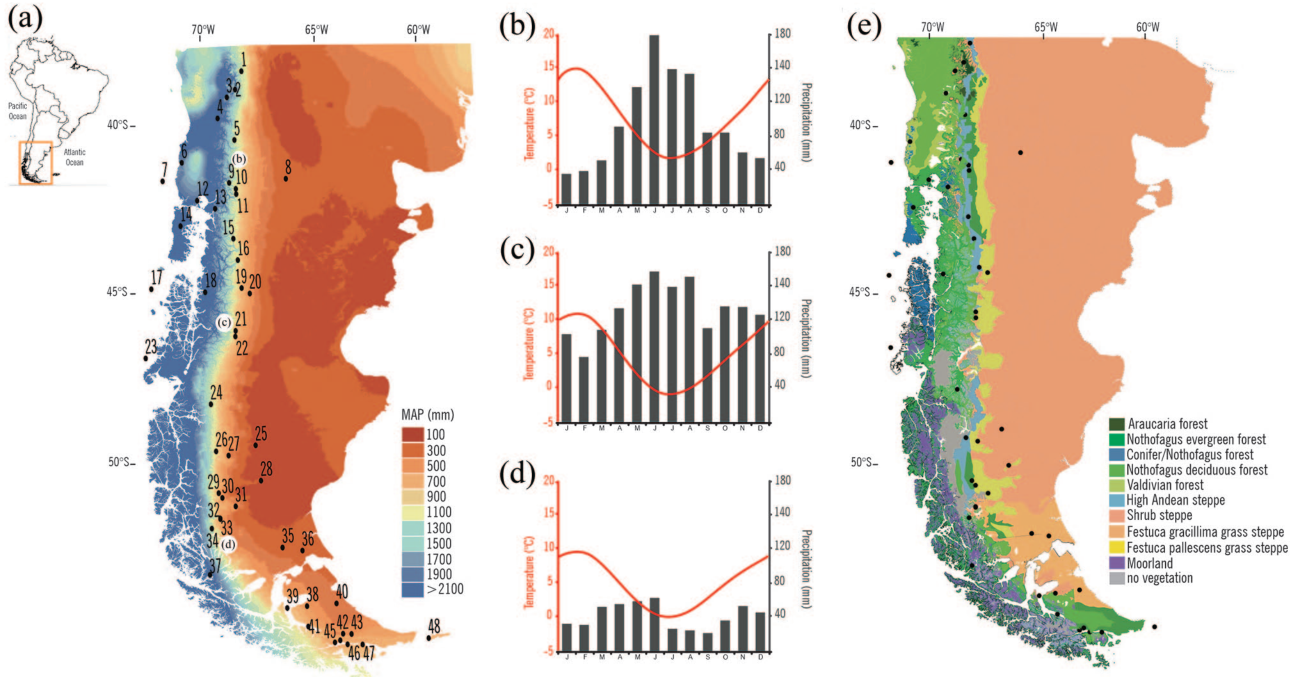

Figure 1. Study area. (a) Mean annual precipitation map from Patagonia (Fick and Hijmans, 2017) showing the location of paleoenvironmental records included in this paper (Supplemental Table S1) and the three locations (b–d) displayed in the climatic diagrams. (b–d) Climatic diagrams of Bariloche (mean annual temperature – MAT – 10°C and annual precipitation – AP – 950 mm/year), Coyhaique (MAT 8°C and AP 1035 mm/year) and Puerto Natales (MAT 6.5°C and AP 450 mm/year), respectively. (e) Vegetation map of Patagonia (modified from Luebert and Pliscoff, 2017; Oyarzabal et al., 2018).

Mensing et al., 2016; Nunn et al., 2007; Plachetka, 2014; Rull, 2019; Williams et al., 2010; Xoplaki et al., 2016), making an interdisciplinary focus indispensable to study this centennial thermal anomaly and its impacts.

In southern South America (38°–55° S), paleoenvironmental archives from Patagonia (Figure 1) show that the Late-Holocene (i.e. last 4200 years) evidenced only minor environmental shifts compared to the substantial climatic, ecological and geomorphological changes that took place during the Holocene (e.g. Ariztegui et al., 2008; Iglesias et al., 2014; Lara et al., 2020; McCulloch et al., 2020; Moreno et al., 2018). However, if considering the last millennia individually, some significant decadal-to-centennial timescale environmental changes are observed (e.g. Flantua et al., 2016; Lara et al., 2020; Morales et al., 2020; Moy et al., 2008). Although the search of a local expression of the MCA yielded scarce and rather imprecise data in the region (Section 1.1), its impact on past human native populations has been the motto of hot debates for over two decades (e.g. Barberena, 2008; Barrientos and Gordón, 2004; Borrero and Franco, 2000; Goñi et al., 2019), mainly focused on the human spatial re-organization due to extreme arid conditions that should have characterized this anomaly. In this context, the present work has three goals: (1) the rigorous search of paleoenvironmental changes resulting from a climatic anomaly coherent with the MCA time window in Patagonia, (2) its characterization in terms of the spatial and temporal distribution of the signals, and (3) the assessment of its potential impact on past human populations.

The medieval climatic anomaly in southern South America

The timing, magnitude, signal, and spatial pattern of the MCA in South America, and particularly in Patagonia, is less clear and ubiquitous that in the Northern Hemisphere (e.g. Ahmed et al., 2015; Daga et al., 2020; Flantua et al., 2016; Gil et al., 2020; Ledru et al., 2013; Lüning et al., 2019; Luterbacher et al., 2011; Mann et al., 2009; Neukom et al., 2011, 2014; Rojas et al., 2016). In the abundant literature related to the MCA since the early work of Lamb (1965), studies in South America provide less than 5% of the scientific bibliography. The lack of documentary records, the fact that South America comprises a large and geographically diverse region with large data gaps, and a rather insufficient dating control of records for the last two millennia may explain such scarcity (e.g. Flantua et al., 2016; Villalba et al., 2009;). Complex connections between the Intertropical Convergence Zone (ITCZ), the South American Summer Monsoon (SASM), the South Atlantic Convergent Zone (SACZ), the El Niño-Southern Oscillation (ENSO), the Southern Annular Mode (SAM), the Pacific Decadal Oscillation (PDO), the Atlantic Multidecadal Oscillation (AMO), southeastern/western Pacific/Atlantic anticyclones, the Southern Westerly Winds Belt (SWWB), and the effect of the Andes as a topographic barrier, as well as the superimposed climatic variability at different time scales over those atmospheric features, have also entangled the comprehension of the MCA signal in South America (e.g. Apaéstegui et al., 2018; Flantua et al., 2016; Haug et al., 2001; Mohtadi et al., 2007; Muñoz et al., 2017; Vuille et al., 2012, and references therein). In turn, these atmospheric and geographical features combined with the characteristics of the most frequently analyzed proxies produce paleoenvironmental records with a higher sensitivity to precipitation than to temperature variations, as well as mixed signals (effective moisture, evaporation, etc.), thus introducing additional limitations for paleoclimatic interpretations.

On average, high-resolution paleoenvironmental data compiled across the Southern Hemisphere show warmer conditions between ca. 1200 and 1350 CE than during subsequent centuries, resulting in a different temporal range than that recorded for the Northern Hemisphere medieval warming and thus supporting the lack of a "globally coherent" MCA timing (Ahmed et al., 2015; Luterbacher et al., 2011; Neukom et al., 2014). More recently, it has also been suggested that the southern latitudes present weaker connections with external forcings, such as insolation or the atmospheric effect produced by volcanism, compared to the Northern Hemisphere, probably due to the more accentuated insularity of the southern hemisphere landmasses (Coronato and Bisigato, 1998; Paruelo et al., 1998). By considering a core period around 1000–1200 CE, warmer anomalies were recently identified in South America by Lüning et al. (2019). In contrast with previous syntheses, they observe a synchronicity between the MCA in the Southern and Northern hemispheres, hence supporting the key role of the ocean-atmospheric system (i.e. ENSO, SAM, PDO, AMO) associated to solar activity as main drivers of this anomaly.

Study region: Patagonia

Patagonia extends from 38° to 55° S, with a maximum west-east extension between 73° and 63° W, comprising both, continental land, and archipelagos (Figure 1). The main atmospheric feature determining the climatic variability of Patagonia are the surface air masses which transport humidity from the Pacific Ocean, while those sourced from the Atlantic Ocean just have a secondary and more coastal role, restricted to easternmost Patagonia. Surface winds coming from the Pacific Ocean (associated to the SWWB) are intercepted by the Andes – reaching 2000 m a.s.l. southwards 38° S – which acts as an orographic barrier forcing the subsidence of the surface air masses. This produces an extreme west-to-east precipitation gradient (e.g. Garreaud et al., 2009), from more than 10,000 mm/year in the Pacific coast to less than 200 mm/year in the plateaus, on the lee side of the Andes (Figure 1a). The influence of the SWWB on Patagonia is, however, complex and heterogeneous. For instance, strong (weak) surface winds increases (decreases) local precipitation in western (eastern) Patagonia (Garreaud et al., 2013). On the other hand, the latitudinal migration of the SWWB following the seasonal shifts of the ITCZ, northwards (southwards) during winter (summer), results in different precipitation regimes throughout Patagonia. Based on the latter, the Andean Patagonia could be divided into three latitudinal areas: (1) a Northern area (38°–44° S) where precipitation mainly falls in winter (AP 950 mm/year) with a MAT of 10°C (Figure 1b); (2) a Central area (44°–50° S, “the core of the SWWB”) where precipitation occurs yearlong (AP 1035 mm/year), with a MAT of 8°C (Figure 1c); and a (3) Southern area (50°–54° S) where precipitation mainly happens during summer (AP 450 mm/year), with a MAT of 6.5°C (Figure 1d). This is particularly important to be acknowledged when regional discussions of present/past climate change are made throughout such a wide latitudinal area to properly look for changes in climate patterns.

Superimposed to the millennial-to-centennial scale variability, the SAM and ENSO are the main sources of inter-annual variability of precipitation in Patagonia (e.g. Garreaud et al., 2009; Montecinos and Aceituno, 2003). Thus, ENSO has a significant effect on precipitation up to 40° S (Northern area) with enhanced (weakened) rainfall during El Niño (La Niña) phases (Montecinos and Aceituno, 2003). On the other hand, the SAM variability influences the whole region with enhanced (weakened) precipitation during positive (negative) phases with different magnitudes according to the latitudinal areas (Garreaud et al., 2013).

Mean annual temperature in extra-Andean Patagonia varies from 14°C to 3°C, thus defining a temperate to cool-temperate region, with a certain continental effect in terms of temperature amplitude and wind activity (Garreaud et al., 2009), contrasting the more ocean-influenced climate of the western Andean slope. In fact, thermal amplitude varies between 16°C in north-center of Patagonia to 5°C in the southern extreme. Mean temperature is related to the latitudinal gradient, but the SWWB also influences temperature patterns; for instance, relatively weaker SWWB over a year result in colder winters and warmer summers, thus increasing the temperature seasonality, and the opposite relation (Coronato and Bisigato, 1998; Paruelo et al., 1998). Short scale climatic variability sources such as the ENSO and SAM could also influence temperature patterns (e.g. Garreaud et al., 2013; Villalba, 2007). For example, under a positive SAM phase, drier and warmer than average conditions occur in the extra-Andean Patagonia.

The Andes rain-shadow effect promotes a significant west-east vegetation change over short distances, from the moorland and evergreen forests at the western slope of the Andes to deciduous forests at the lee side, while grass and shrub steppes cover much of the extra-Andean Patagonia, setting the meridional section of the South American Arid Diagonal (Figure 1e; Gourou and Papy, 1966). On the other hand, considerable north-to-south vegetation changes, particularly concerning the forests composition at both sides of the Andes, are also observed (Figure 1e). Thus, northernmost forests in Patagonia are those dominated by *Araucaria araucana* in both sides of the Andes (38°–39° S) followed by the Valdivian Forest (39°–41° S), mainly developed at the western slope while presenting a restricted distribution on the lee side of the Andes and close to the Argentina-Chile international border. Then, conifer (mainly *Austrocedrus*)-*Nothofagus* forests develop between 41° and 43° S at both sides of the Andes followed southwards (43°–54° S) by *Nothofagus* spp. dominated forests which present a variety of species with the evergreen (deciduous) ones dominating the western (eastern) forests.

These biogeographical and climatic conditions provided the scenario for the cultural and economic evolution of native populations during the last millennia before the European arrival in Patagonia. Broadly described, these societies comprised diverse groups of hunter-gatherers with a pedestrian mobility across large areas, including vast grass steppes and dense forests, east and west of Andes, respectively inhabited the region until the European colonization. During the Late-Holocene, the archeological record shows evidence of both brief open-air and shelter occupations by highly mobile people, developed a subsistence system well-adapted to “extreme environments” (Scheinsohn, 2018) through diverse strategies that include specialized hunting-fishing technologies, mixed diets, low demographic populations, long-network interactions, and flexible land-use patterns (e.g. Barberena et al., 2015; Borrero et al., 2009; Franco et al., 2018; García Guraieb et al., 2015; Méndez et al., 2014; Perez et al., 2016; San Roman et al., 2016). Indeed, when the Spanish conquest began (16th century), Europeans broadly described two main distinctive ways of hunter/fisher-gatherer adaptations: one based on terrestrial resources (i.e. *Lama guanicoe* along small mammals, birds, littoral, and marine resources), inhabiting inland and coasts; and another including groups highly specialized in marine ecosystems, with navigation systems, distributed along the pacific archipelagos to the southern tip of the continent (e.g. Martinic, 1995; Nacuzzi, 2005; Orquera and Piana, 1995), though a more diverse socio-economic landscape has been reconstructed based on historical, zooarchaeological, and isotopic records (e.g. Borrero et al., 2011; Zangrando et al., 2009). These successful ways of life which dealt with diverse, extreme and changing environments for over 13,000 years ended abruptly due to the aggressive geopolitical expansion and the spread of diseases brought by the European colonization process (e.g. Boschin and Fernández, 2020; Fugassa and Guichón, 2004).

Methodological and theoretical premises

A compilation of peer-reviewed paleoenvironmental studies from Patagonia conducted in decadal-to-centennial timescale resolution, from continuous archives (i.e. lakes, peatbogs/mires, marine cores, tree-rings, and cave speleothems) was performed. From the

Table 1. Threefold criteria applied to recorded environmental changes (Supplemental Table S1) in order to identify the MCA, where the validation of (step 1) conditioned the application of the following filters (steps 2 and 3) and so on.

Quality assessment						
(1) Data interpretation			(2) Chronological control		(3) Time range adequacy	
Consistent	Non-conclusive	Ambiguous	High-moderate	Low	Duration	Onset
Inferences derived from single-proxy studies which presents specific modern analogs or multiproxy studies whose different lines of evidence are coherence among each other	Single-proxy inferences with a lack of an explicit modern analogs or multiproxy analyses with inconsistencies among proxies	Re-studied sites with divergent conclusions	Studies which present (a) an age-depth-model built with ⩾3 ages for the last 1500 years, and (b) a multi-decadal time resolution or less (years represented by each sample, resulting from the number of analyzed samples for the last 1500 years)	Studies which present (a) an age-depth-model built with ⩽2 ages for the last 1500 years, and (b) a centennial time resolution	Temporal range (years) in which the observed environmental change take place	Beginning of the environmental change (CE)
Absence of erosional unconformities, tephra deposits immediately above or below the section understudy, mass movement processes, anthropogenic disturbance signals, or any other syn/post-depositional process	Presence of any syn/post-depositional process					
(Step 1) Filer: "consistent" interpretations			(Step 2) Filter: high/moderate chronological controls		(Step 3) Filter: durations between 100 and 500 years and onsets between ca. 700 and 1000 CE	

total literature, only cases where a "conspicuous environmental change" was observed around the MCA window (see below), either in the original publications or observed by us in this work, were selected (Supplemental Table S1). In the case of records presenting annual resolution (i.e. tree-rings and cave speleothems), a decadal smooth was applied by calculating a 10 year-moving average to improve the comparison with the most abundant multidecadal-to-centennial paleoenvironmental records. A wider temporal range of the MCA, between 700 and 1400 CE, was considered due to possible variations arising from local lags (i.e. teleconnections, proxy sensitivity/resilience), the age-depth-model construction and/or other theoretical and methodological premises. In order to homogenize a large and diverse regional information, a "conspicuous environmental change" was defined qualitatively, as a relative (i.e. a drop/peak in the values of a certain proxy), noticeable, abrupt, and temporally discrete shift in the proxy data (e.g. pollen, charcoal, diatoms, isotopes, geochemistry, magnetic susceptibility, etc.) or the reconstructed climatic parameter (i.e. temperature, precipitation, moisture). Since minor geomorphological changes occurred during the last 1500 years (ignoring those related to the Little Ice Age and the 20th century warming acceleration), and proxy data inferences are robust (see below), it is assumed that such conspicuous environmental changes are likely caused by a climatic anomaly.

A quality assessment of (1) data interpretation, (2) chronological control, and (3) time range adequacy to the MCA time window was carried out by a graphical examination of compiled data (Table 1 and Supplemental Table S1). Rather than a quality assessment of the research per se, the proposed criteria particularly refer to the accuracy of climatic inferences raised from an environmental change (step 1) and the strength of its linkage with the MCA (steps 2 and 3). Table 1 details all the criteria, where the validation of "step 1" restricts the number of records which are filtered by following criteria (steps 2 and 3).

Possible causal connections between paleoenvironmental and human changes are based on the theoretical premise that changes in human behavior are expected if climatic shifts impact or threaten the abundance, availability, and spatio-temporal distribution of key resources for human subsistence such as food, water, or raw materials (Binford, 2001; Darlington, 1978; Yellen, 1977). The tempo and direction of human-change will thus depend on (1) the speed, duration and magnitude of the climatic anomaly; (2) the environmental information already acquired by people through time (including past risk-buffer experiences), and the preexisting spectrum of human-adaptive strategies (e.g. technology, social networks, mobility patterns and all sort of socio-economic and political practices) (e.g. Dincauze, 2000; Halstead and O'Shea, 1989; Odling-Smee et al., 2003; Oliver-Smith, 1996; Veth, 2005).

The human resilience capacity, namely, the magnitude of disturbance that an organism or a population can dynamically absorb before changing to a different state, is central when facing environmental shifts (e.g. Berkes et al., 2000; Crombé and Robinson, 2017). This capacity is also related and constrained by the resilience of ecosystems (i.e. the capacity to respond to a disturbance by resisting damage and recovering quickly; Holling, 1973). This does not imply that the system remains unchanged, but rather that the system possesses a certain degree of flexibility to adapt to moderated levels of change, as well as the ability to reset and adjust to new conditions without losing its basic functionality (or, from the human perspective, the "ecosystem services") (Yacobaccio et al., 2017). If climate changes are severe enough, they could produce landscape fragmentation eventually leading to habitat loss, implying a process of random isolation of biological variants that affects the way in how that locus is perceived and used by human populations (Smith, 2013).

The study of past systems poses two specific methodological challenges for the analyses of human-environmental interactions:

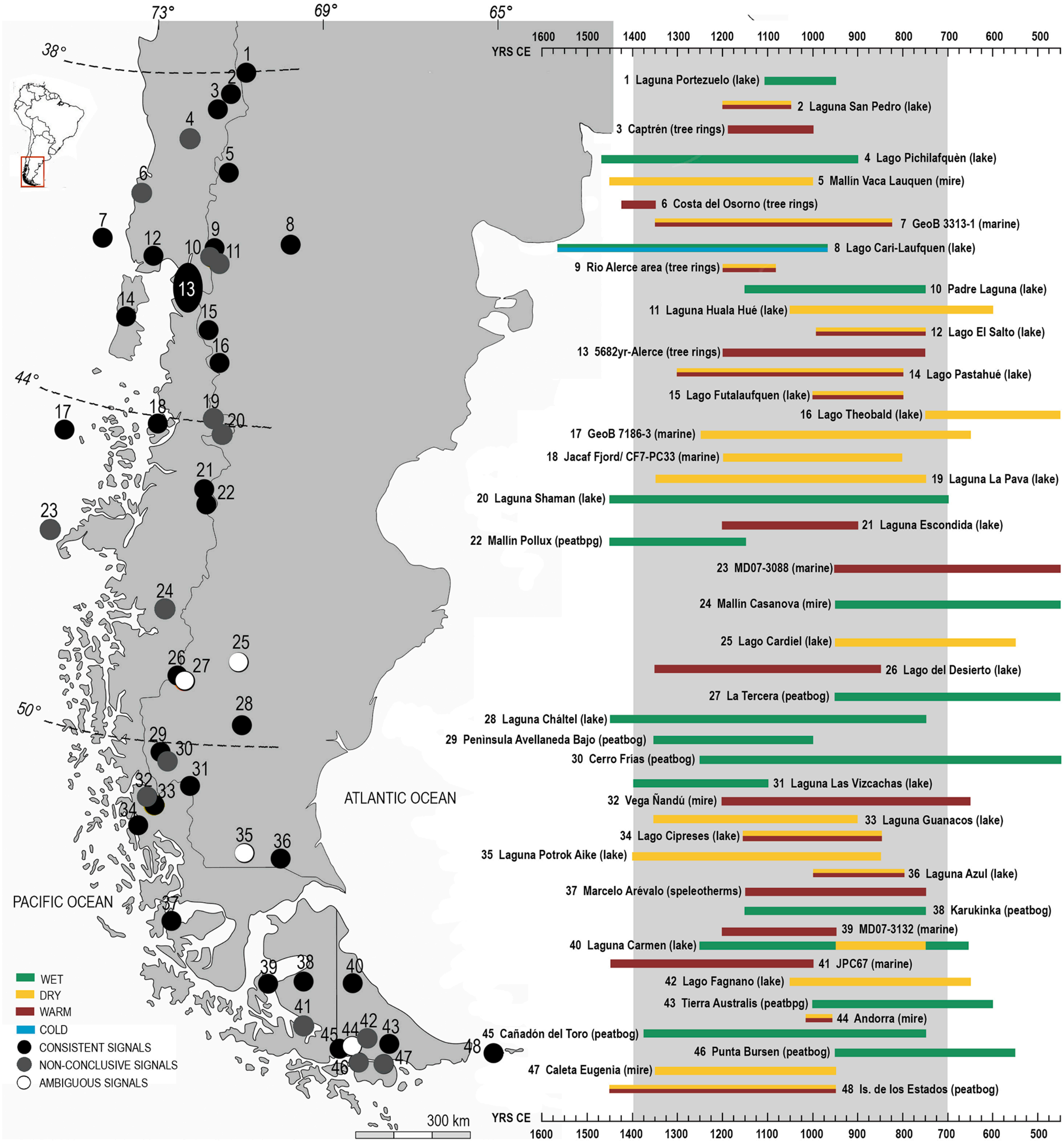

Figure 2. Map with paleoenvironmental sites included in this paper ($N=48$) showing the climatic inferences derived from the environmental changes around the MCA temporal window (gray vertical shadow). See references and full data in Supplemental Table S1.

(1) both environmental dynamics and human behaviors are interpreted indirectly, from proxy data and the archeological/documental record, respectively; and (2) low temporal resolution in the available archives often precludes causal inferences between these systems (e.g. Barberena et al., 2015, 2017; de Porras et al., 2021; Dincauze, 2000; Holdaway and Fanning, 2010; Holdaway and Porch, 1995; Kinahan, 2016; Méndez et al., 2015; Mitchell, 2017; Morales et al., 2009; Ozán and Pallo, 2019; Smith et al., 2008).

Results: Disentangling the MCA in Patagonia

Signal

Figures 2 and 3 summarize the spatial distribution of 48 climatic signals derived from paleoenvironmental changes recorded around the MCA time window (Supplemental Table S1). Broadly, most of the cases yield wet climatic signals ($N=16$), followed by dry records ($N=11$), dry and warm ($N=10$), and warm ones ($N=10$) (Figure 3a). There is only one record showing a wet and cold climatic signal (ID8). Data are by far more abundant in forests ($N=22$) and forests-grass steppes ecotones (11), at both sides of the Andes, than in the extra-Andean Patagonian steppes ($N=9$) likely due to differences in the availability of continuous paleoenvironmental archives such as lakes, peatbogs and mires. By comparing relative frequencies of climatic signals between these main phytogeographic units (Figure 3b), Patagonian forests show rather equal proportions of wet, warm, and dry and warm signals, with a relatively less representation of dry conditions. Ecotones are dominated by wet and dry signals, with a smaller proportion of warm and dry-warm conditions. Steppes show a dominance of wet conditions, followed by dry and dry and warm signals (there

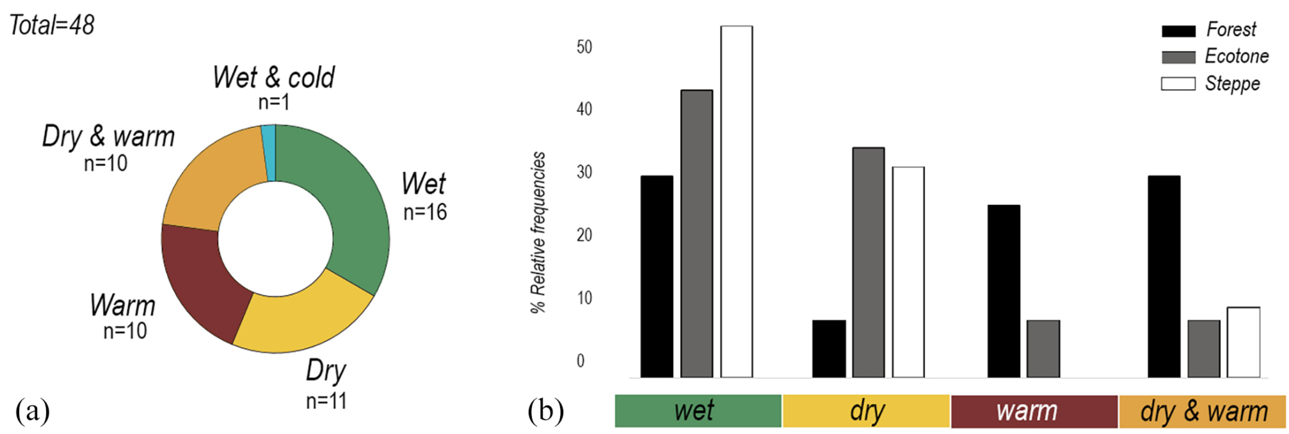

Figure 3. (a) Total climatic signals recorded during the MCA. (b) Relative frequencies of total climatic signals organized by main phytogeographic units (marine records were omitted and the "wet and cold" signal was merged into the "wet" category).

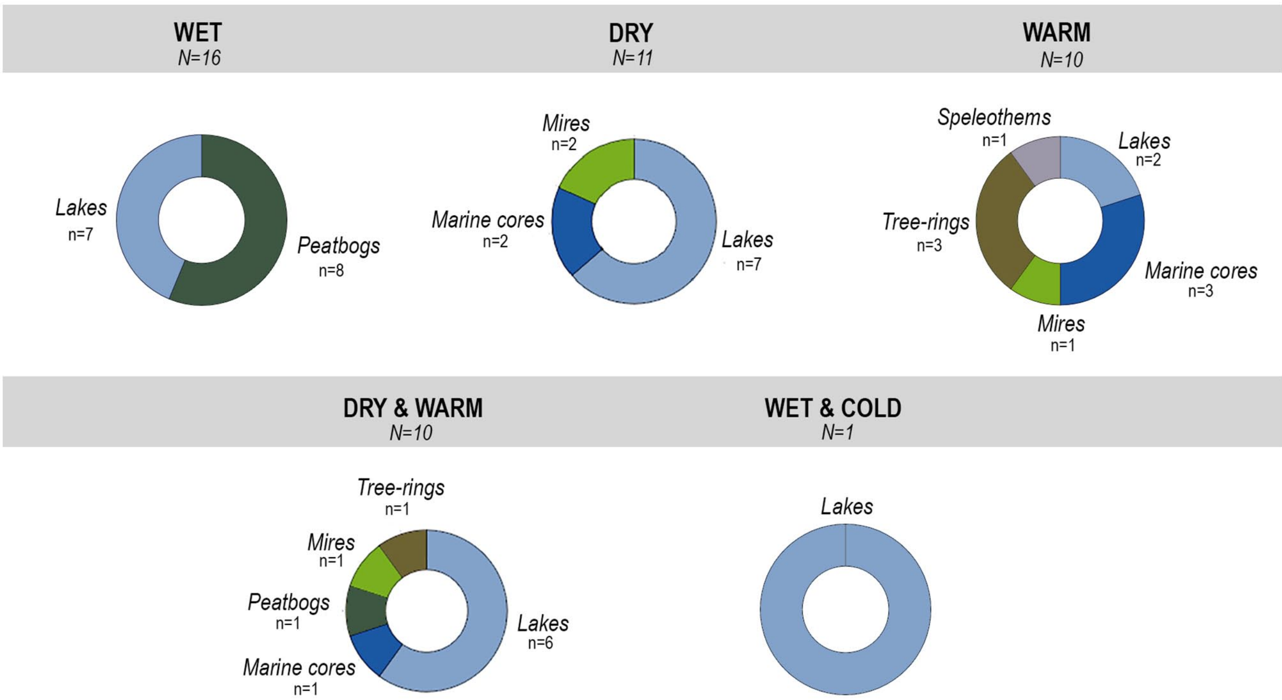

Figure 4. Climatic signals recorded during the MCA organized by type of archives.

are nor records suggesting warm conditions) (Figure 3b). Hence, despite of the fact that wet signals dominate in the three phytogeographical units, dry and/or warm climatic anomalies (considered together since temperature conditions moisture) are the most represented.

Climatic signals do not present a defined latitudinal pattern either, since the moderate increase in wet signals below latitude 45° S could actually result from the type of archive (i.e. peatbogs). Notably, peatbog-based studies, only located southwards 45° S (Figure 2), always yield wet signals, except for one case (Figure 4). Moreover, whereas dry and/or warm conditions have been inferred from diverse archives (i.e. tree-rings, speleothems, lakes, marine cores, mires, peatbogs), wet signals only result from lakes and peatbogs contexts (Figure 4). This fact warns about a likely existence of a bias -due to proxy over-sensitivity – derived from the type of archive (see also Section 4.1).

Interpretations that arise from single or multiproxy (⩾2) studies also suggest a moderate bias in the climatic signal due to an over-representation of wet anomalies in single-proxy inferences, and/or an under-representation of dry/warm signatures (Figure 5a, Supplemental Table S2). In turn, single-proxy studies are dominated by biological proxies such as diatoms, chironomids, ostracods, but particularly pollen and/or non-pollen palynomorphs, which also seem to be more prone to detect moisture changes (Figure 5b; Supplemental Table S2). On the other hand, data also indicate that inorganic proxies (i.e. geochemistry, isotopes, sedimentology, magnetic susceptibility, mineralogy) are more sensitive to record warm conditions (Figure 5a). In sum, climatic signals here displayed may have a moderate bias toward wet anomalies due to the number and type of proxies considered in the interpretation, as well as the type of archive understudy.

In this regard, by applying the quality filer of data interpretation (Table 1), where only "consistent" interpretations are selected (N=30), records depicting wet conditions are reduced considerably, and thus dry and/or warm climatic signals become more remarkable (Figure 6a), particularly from forests and forest-steppe ecotones (Figure 6b). The following section is based on this set of records.

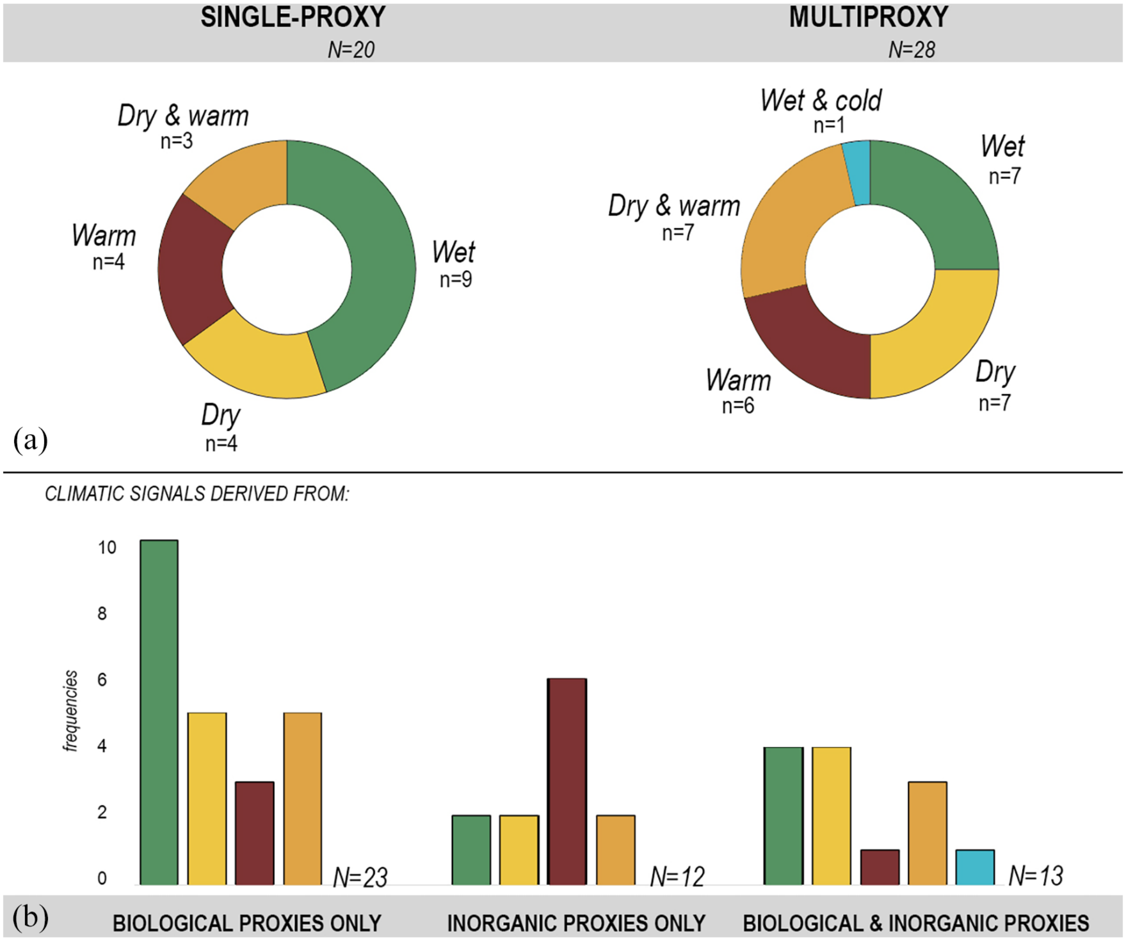

Figure 5. Climatic inferences based on (a) single-proxy and multiproxy analyses (⩾2). (b) Frequencies of climatic signals derived from studies which only considered biological proxies (i.e. pollen and/or non-pollen palynomorphs, charcoal, diatoms, chironomids, ostracods, phytoliths, tree-rings), inorganic proxies (geo/bio-chemical, isotopes, mineralogy, sedimentology, magnetic susceptibility), or a combination of both biological and inorganic proxies. See color references in Figure 3 (see also Supplemental Table S2).

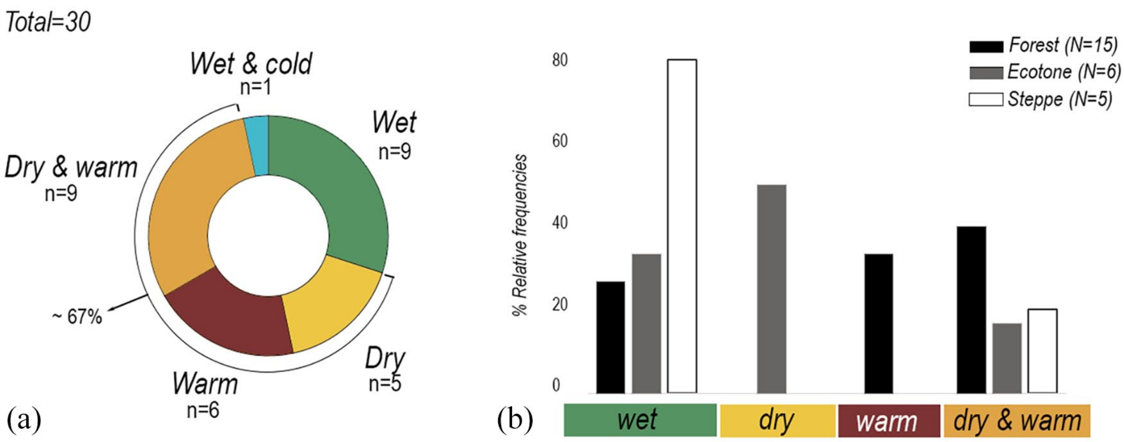

Figure 6. (a) Distribution of climatic signals after applying the data interpretation filter (Table 1), where only "consistent" climatic interpretations are selected (see location in Figure 2). (b) "Consistent" signals organized by main phytogeographical units (marine records are excluded).

Timing

From the total of "consistent" interpretations (Figure 6), studies with a "high/moderate" chronological control presenting an adequate fit within the MCA time range (Table 1) were selected (Figure 7; Table 2). Therefore, Figure 7 shows a set of 18 records fulfilling the three quality filers (Table 1). In terms of their spatial distribution, data are distributed from latitude 38° to 53° S, mainly in forests and ecotones, with one exception located in the steppe. Such climatic anomalies range between 750 and 1350 CE, with a core period between ca. 900 and 1200 CE. Consistently, all the 18 records, comprise dry and/or warm conditions, with the exception of two wet signals.

Discussion

The MCA in Patagonia

After rigorous evaluation, climatic anomalies presented in Figure 7 (Table 2) fit well with the MCA global timing and signal. Its spatial

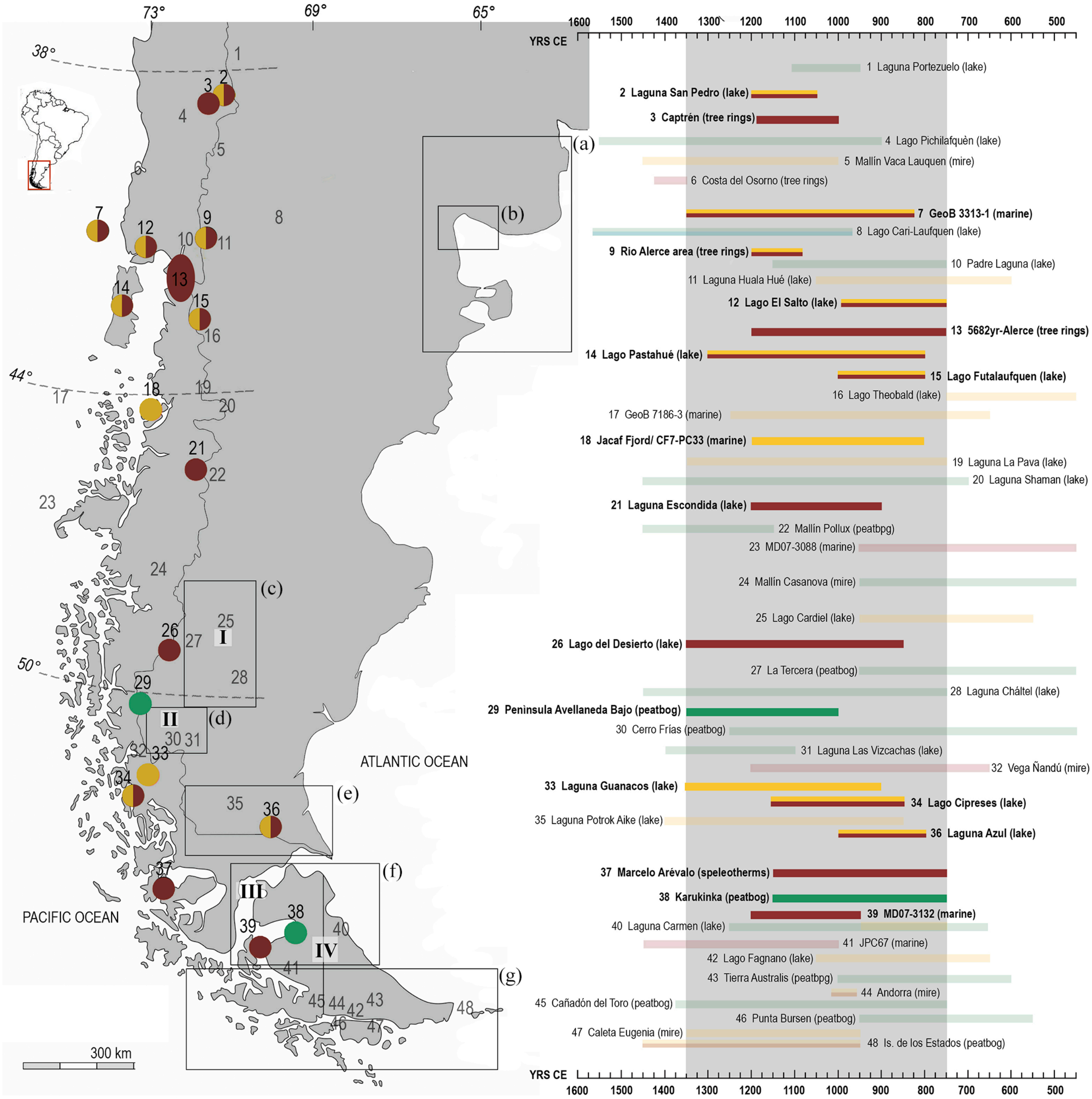

Figure 7. Selected climatic anomalies accurately associated with the MCA time window, based on quality criteria detailed in Table 1. The gray vertical shadow delimits the temporal ranges of selected anomalies (750–1350 CE). Squares indicate archeological areas where causal relationships between changes in past human populations and the MCA aridity were proposed (Section 4.2). (a) Barrientos and Gordón (2004), Gordón (2015). (b) Favier-Dubois and Kokot (2011). (c) Goñi et al. (2000), Belardi et al. (2003), Cassiodoro et al. (2013), García Guraieb et al. (2015), Rindel et al. (2017), Goñi et al. (2019). (d) Borrero and Franco (2000), Franco et al. (2004, 2018). (e) Barberena (2008), Pallo and Ozán (2014). (f) Pallo and Ozán (2014), Ozán and Pallo (2019). (g) Ozán and Pallo (2019). I – Lago Cardiel. II – Lago Argentino. III – Magellan Strait. IV – Isla Grande de Tierra del Fuego.

pattern across different latitudinal bands (Section 1.2), between 38°26′ and 53°43′ S, and across diverse phytogeographic units (i.e. forests, ecotones, steppes), indicate a macro-regional expression. Suggested triggers are – in turn – consistent with the state of the art-perspective about the topic (i.e. solar irradiance, poleward displacement of the SWWB, positive SAM phase; Supplemental Table S1). The slight predominance of warm signals could either suggest that dry conditions are related to such thermal anomalies, and/or those paleoenvironmental proxies are more sensitive to precipitation than to temperature (Sections 1.1 and 3.1).

The lack of ubiquitous evidence of the MCA in Patagonia (Figure 2, Supplemental Table S1) may thus result from theoretical and methodological issues, as became evidenced after the quality-filter. Undoubtedly, single-proxy inferences, poor chronological controls for the last millennia, along with environmental signals which characterized large catchment areas (e.g. marine cores, large lakes), ambiguity of proxy interpretation and/or post-depositional processes could hamper the recognition of climatic signals or misguide their interpretation (Figures 4 and 5). These issues could also explain other paleoenvironmental studies which do not even observe a "climatic anomaly" around the MCA time window in Patagonia, which are therefore not treated here (e.g. Bianchi and Ariztegui, 2012; Fesq-Martin et al., 2004; Lüning et al., 2019; Markgraf and Huber, 2010; Markgraf et al., 2003; Musotto et al., 2016, 2017; Pesce and Moreno, 2014; Whitlock et al., 2006; and references therein).

We should not expect, however, a ubiquitous expression of the MCA in Patagonia, since local environmental signals resulting

Table 2. Main data of paleoenvironmental studies ($N=18$) after "quality filters" (Figure 5).

ID site (archive, phyto-geographic unit)	Time range (CE)	Proxy change	Climatic signal	References
2. Laguna San Pedro (lake, Araucaria forest-grass steppe ecotone)	1050–1200	More negative *Nothofagus dombeyi*/Poaceae index, high charcoal content, and high sedimentation rates	Dry and warm	Fletcher and Moreno (2012); this work
3. Captrén (tree-rings, Conifer/*Nothofagus* forest)	1000–1180	Relatively wider tree-rings	Warm	Aguilera-Betti et al. (2017), Lüning et al. (2019); this work
7. GeoB 3313-1 (marine, no vegetation)	825–1350	High Fe content, high-crystallinity smectite, low C_{org} (low productivity), high SST and SSS	Dry and warm	Lamy et al. (2001, 2002), Varma et al. (2011); this work
9. Rio Alerce area (tree-rings, Conifer/*Nothofagus* forest)	1080–1250	Relatively wider tree-rings	Dry and warm	Villalba (1990, 1994)
12. Lago El Salto (lake, deciduous forest)	750–990	*Nothofagus dombeyi* drop. *Weinmania trichosperma* and *Eucryphia*/*Caldcluvia* peak. Increase in *Aristotelia chilensis*. Charcoal drop.	Dry and warm	Moreno and Videla (2016); this work
13. 5682 year-Alerce (tree-rings, deciduous forest)	750–1200	Relatively wider tree-rings	Warm	Lara et al. (2020); this work
14. Lago Pastahué (lake, Deciduous forest)	800–1300	High abundance of thermophilic taxa. Low abundance of *Myrceugenia* and *Amomyrtus*, and gradual decrease of Elaeocarpaceae. Chironomids adapted to warm conditions (i.e. *Polypedilum*).	Dry and warm	Troncoso Castro et al. (2019)
15. Lago Futalaufquen (lake, deciduous forest)	800–1000	Greenish sediments (higher oxygen consumption). Organic matter, $\delta^{13}C$ and $\delta^{15}N$ increase (higher productivity, peak at 900 CE). Increase in diatoms. Al, Fe, Ti, and Mg concentrations decrease.	Dry and warm	Daga et al. (2020)
18. Jacaf Fjord/CF7-PC33 (marine-fjord, no vegetation)	800–1200	Lower C/N ratios. drop in the mass accumulation rate of leaf waxes (1050–1200 CE). Moderate decline in $\delta^{13}C$ values (910–1200 CE).	Dry	Sepúlveda et al. (2009); this work
21. Laguna Escondida (lake, deciduous forest)	900–1200	Higher temperatures based on reconstructed annual temperature anomalies derived from bSi flux	Warm	After Elbert et al. (2013)
26. Lago del Desierto (lake, deciduous forest)	850–1350	New source of inputs: coarser materials, high Ca-enrichment, and Ca/Ti ratio, changes in magnetic susceptibility: glacial melting	Warm	Kastner et al. (2010) and Lüning et al. (2019)
29. Península Avellaneda Bajo (peatbog, deciduous forest)	1000–1350	*Nothofagus dombeyi* and Pteridophyta peak. Low Poaceae and Caryophyllaceae content. High water balance index.	Wet	After Echeverria et al. (2014)
33. Laguna Guanaco (lake, deciduous forest-grass steppe ecotone)	900–1350	Higher $\delta^{18}O$-*Pisidium* values, more positive $\delta^{18}O$-fine grain values and relatively higher $\%CaCO_3$ (drop in-between) (1000–1200 CE). Low *Nothofagus dombeyi*/Poaceae and Apiaceae undiff./Asteraceae subf. Asteroideae ratios.	Dry	After Moy et al. (2008), Moreno et al. (2009)
34. Lago Cipreses (lake, deciduous forest)	850–1150	Increase on non-arboreal pollen, charcoal, Cyperaceae, siliciclastic density, *Escallonia*, and *Blechnum*; and a decrease of *Nothofagus dombeyi*	Dry	Moreno et al. (2014, 2018)
36. Laguna Azul (lake, Grass steppe)	800–1000	High %TIC, Ca/Ti values and $\delta 13C_{org}$, eutrophic conditions (relatively lower lake level)	Dry and warm	Zolitschka et al. (2019)
37. Marcelo Arévalo (speleothems, Moorland)	750–1150	High $\delta^{18}O$ and Mg/Ca (two step increase from 800 to 1075 CE)	Warm	After Mühlinghaus et al. (2008), Schimpf et al. (2011)
38. Karukinka (peatbog, deciduous forest-grass steppe ecotone)	750–1150	High water levels inferred from testate ameba transfer function	Wet	van Bellen et al. (2016); this work
39. MD07-3132 (marine-fjord, no vegetation)	950–1200	High STT. Hight terrestrial organic matter (precipitations). Peak of biogenic opal and $CaCO_3$ (high productivity and/or salinity change). Drop in marine organic carbon (low productivity).	Warm	Aracena et al. (2015), Lüning et al. (2019); this work

Source: See Supplemental Table S1 for a full description.

from specific geomorphologies or ecological configurations, the ecosystem resilience and sensitivity and the complex teleconnections between atmospheric, oceanic, geological, and biological processes may hide or obliterate a climatic phenomenon. Indeed, this may explain wet records associated to the MCA (Figure 7, ID 29 and ID 38; re-analyses after Echeverria et al., 2014; van Bellen et al., 2016; respectively), as well as many others wet signals which might have taken placed around the MCA, but they are not related to this phenomenon. For instance, anti-phased precipitation patterns between the western Andean slope and the eastern extra-Andean region of Patagonia, as a result of the forced subsidence of surface winds, could have played a role during the MCA in Patagonia (Fey et al., 2009; Garreaud et al., 2013; Lara and Villalba, 1993; Villalba, 1990, 1994). This effect of local environmental signals could also explain some of the wet signals, but particularly those accurately related to the MCA (Figure 7), which derive from peatbog-based studies, a type of archive that seems to be more sensitive to record wet signals (Figure 3) (e.g. Aranbarri et al., 2014; Charman et al., 2009; Morales et al., 2018; Schittek et al., 2016).

The impact of the MCA on past human populations from Patagonia

Low temporal resolution analyses in archeology (i.e. centennial to multi-centennial) emerge as the main problem when human responses to a specific environmental phenomenon are explored, since a careful evaluation of the synchronicity between anthropic and natural processes must first be determined before discussing possible causal relations (e.g. Holdaway and Fanning, 2010; Huang et al., 2020; Marchant et al., 2018; Sandweiss and Quilter, 2012; Smith et al., 2008). For this reason, analyses of broad human-environmental trends have been a more common approach in Patagonia to explain changes in human trajectories along the Holocene (e.g. Barberena et al., 2015, 2017; Belardi et al., 2003; Favier-Dubois, 2003; Fernández et al., 2020a; Franco et al., 2018; Goñi et al., 2019; Martin and Borrero, 2017; Morello et al., 2012; Virginia Mancini and Graham, 2014). However, based on ecological perspectives, specific human responses to the MCA in Patagonia have been proposed (Figure 7). By integrating previous paleoenvironmental analyses, these archeological hypotheses are discussed next. Some records which could not be ascribed to the MCA are also considered, since they are still relevant from a human biogeographical perspective.

Patagonian steppes: Making sense of the MCA puzzle. An increase in population density, intense occupations of places with abundant and predictable resources, and northward migrations of human groups from northeastern Patagonia (Figure 7a, 39°–42° S) have been related to environmental effects of the MCA arid conditions (Barrientos and Gordón, 2004; Gordón, 2015), particularly around 1000 CE (following the Cardiel record; Stine, 1994; ID 25). In the same way, dry conditions ascribed to the MCA, also around 1000 CE (according to tree-rings data; Villalba, 1990, 1994; ID 9), were proposed to explain a human concentration around coastal springs, with a concomitant decrease in residential mobility (Figure 7b, 40° S) (Favier-Dubois and Kokot, 2011). However, our results indicate that the closest paleoenvironmental records with robust evidence of the MCA (Figure 7; ID 2, 3, 9) are located in Conifer/*Nothofagus* forests and Araucaria forest-grass steppe ecotones, above 900 m a.s.l. and more than 500 km away from these steppes of northern Patagononia (Table 2 and Supplemental Table S1), hampering the possibility of extrapolating the climatic reconstructions. Indeed, relatively moister conditions during the MCA are recorded in closer archives from the grass-shrub steppe (Figure 2, ID 8; c.f., Marcos et al., 2012) and the neighbor Pampean grasslands (Stutz et al., 2010, 2012).

An archeological research program targeting the impact of the MCA on mobile human societies has been developed in the shrub steppes from southern Patagonia in Santa Cruz province (Figure 7c) (e.g. Belardi et al., 2003; Cassiodoro et al., 2013; García Guraieb et al., 2015; Goñi et al., 2000). These authors have argued that a spatio-temporal scarcity of key resources such as water, food, and fuel due to arid conditions apparently encompassing the last 2500 BP, but particularly during the MCA (temporally constrained at ca. 1020–1230 CE, sensu Stine, 1994), triggered a macro-regional decrease in residential mobility, the concentration of residential occupations in low lake-basins, and an increase of logistic movements (Cassiodoro et al., 2013; García Guraieb et al., 2015; Goñi et al., 2019; Rindel et al., 2017).

However, our analysis of paleoenvironmental archives does not support the evidence for a dry MCA in the Lago Cardiel record, the main source of data feeding these archeological discussions. In the Lago Cardiel record, dry conditions are only registered between ca. 550 and 950 CE (after Markgraf et al., 2003), a lapse falling outside the MCA time range. Moreover, a low chronological control resulting from a centennial temporal resolution and a lack of radiocarbon dates for the last 1500 years does not allow a proper MCA discussion focused on the Cardiel record (Supplemental Table S1). Finally, neither geomorphological (Quade and Kaplan, 2017), ostracod-based (Ramos et al., 2019), seismic, nor magnetic studies from the Lago Cardiel (Ariztegui et al., 2014; Beres et al., 2008; Gilli et al., 2001, 2004, 2005b) recorded an environmental change during the MCA (Supplemental Table S1). The only evidence supporting arid conditions during the MCA at Lago Cardiel is based on relict tree stumps found on the lake margins, dated around 1100 CE (recalibrated after Stine, 1994). We consider that this evidence is insufficient to sustain local arid conditions during the MCA, particularly when confronted with the continuous core sequence obtained from the lake (Markgraf et al., 2003; Ramos et al., 2019).

The record of Lago del Desierto (Kastner et al., 2010; ID 26), ~120 km east of Lago Cardiel (Figure 8), shows a MCA-related warm anomaly between ca. 850 and 1350 CE, but in the deciduous forest. Therefore, its extrapolation to the easternmost steppes may be limited of limited value if we consider the broad geographical configuration of the region, where opposite climatic signals between western forests and eastern steppes may exist (Section 1.2). Notably, many “consistent” records from latitude 47°39′ to 50°40′ S actually show wet anomalies around this period, such as Laguna Cháltel (Ohlendorf et al., 2014; this work; ID 28, 750–1450 CE, grass steppe), Península Avellaneda Bajo (after Echeverria et al., 2014; ID 29, ca.1000–1350 CE, deciduous forest), and Laguna Las Vizcachas (Fey et al., 2009; ID 31, ca. 1100–1400 CE, grass steppe). Though less robustly according to our critical analysis, records from Mallín Casanova (Iglesias et al., 2016, 2018; this work; ID 24, ca. 450–950 CE, evergreen forest), La Tercera (Bamonte and Mancini, 2011; this work; ID 27, ca. 450–950 CE, grass-shrub steppe), and Cerro Frias (e.g. Tonello et al., 2009; this work; ID 30, ca. 450–1250 CE, deciduous forest-grass steppe ecotone) also indicate wet conditions during the MCA (Figure 8; Supplemental Table S1). It is still unclear, however, to what extent these local moister conditions are representative of a wider region, if they have certain teleconnections with the MCA, or they rather represent independent microenvironmental azonal signatures. In any case, these wet records are more frequent and ubiquitous than dry conditions in southern Patagonia. This is particularly relevant for considering human-environmental discussions in Patagonia, since the present regional analysis of high-quality environmental data does not support an extreme and/or homogeneous arid scenario, as usually invoked to explain the archeological changes observed at this latitude during the MCA (Figure 8).

The Lago Argentino area (Figure 7d), ~140 km southwards of Lago Cardiel, has also provided evidence utilized to discuss archeological hypotheses related to the MCA time-window. Discontinuous human occupations around 1000 CE have been proposed due to the MCA-related aridity, which would have installed biogeographical barriers for the human circulation (Borrero and Franco, 2000; Franco et al., 2004), whereas wet intervals would have promoted the human occupation of the area (Franco et al., 2018). Both wet conditions (i.e. ID 28, 29, 30, 31) as well as dry and/or warm robust records related to the MCA are registered near the Lago Argentino (Figure 8). The latter comprise Laguna Guanaco (after Moreno et al., 2009; Moy et al., 2008; ID 33, ca. 900–1350 CE, deciduous forest-grass steppe ecotone), Lago Cipreses (Moreno et al., 2014, 2018; ID 34, ca. 850–1150 CE, deciduous forest), and the less accurate record of Vega Ñandú (Villa-Martínez and Moreno, 2007; this work; ca. 650–1200 CE, deciduous forest-grass steppe ecotone).

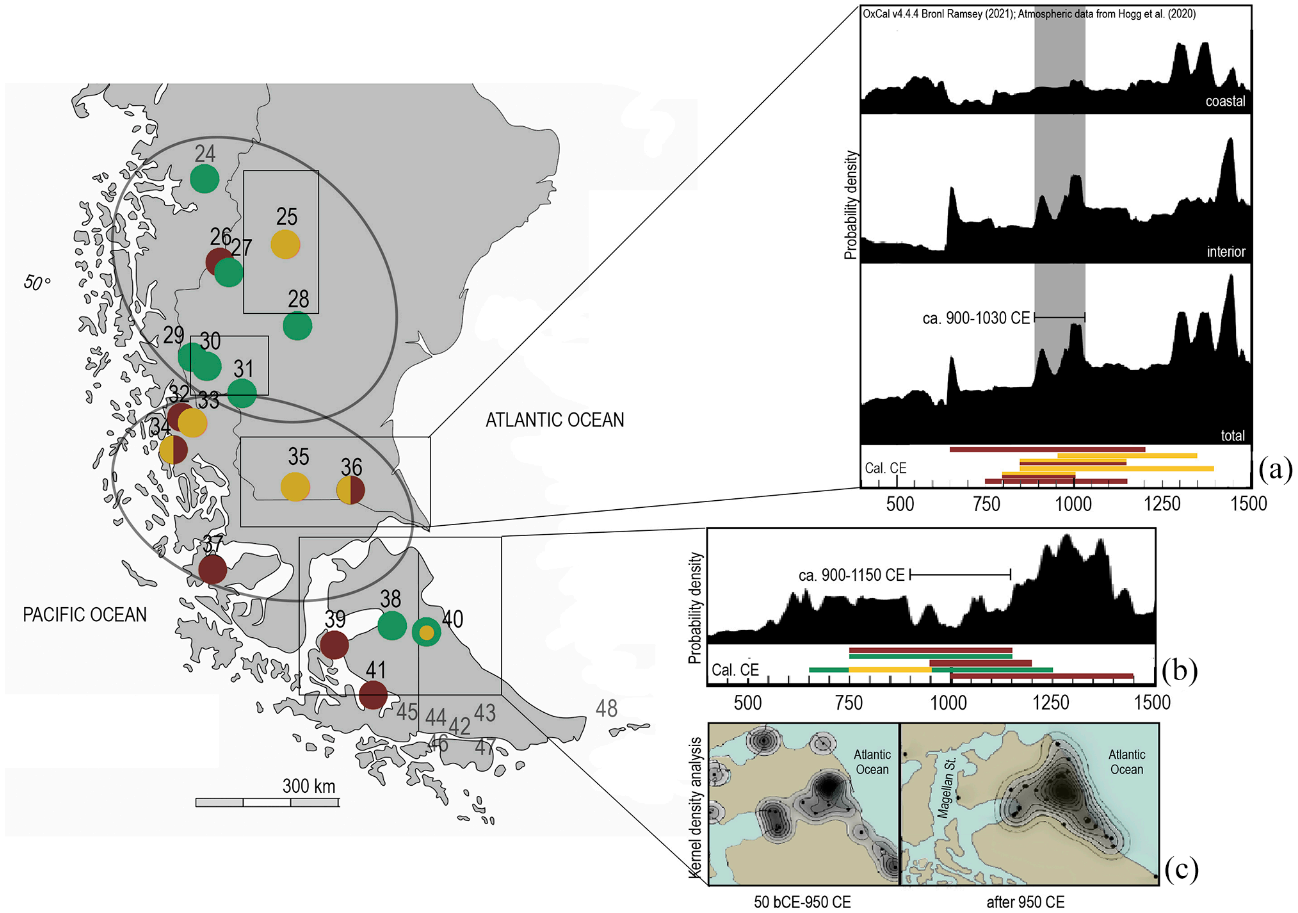

Figure 8. Southern Patagonia map with all climatic signals (no quality filters applied) around the MCA (Supplemental Table S1). The ovals indicate two different environmental scenarios (responses?) during the arid/warm climatic anomaly. (a) Normalized sum probability plots of archeological radiocarbon dates from southen continental Ptagonia (grass steppes), divided by coastal vs. interior archeological sites (modified after Pallo and Ozán, 2014). (b) Sum probability distribution from northern steppes and ecotones of Tierra del Fuego (modified after Ozán and Pallo, 2019). (c) Kernel density analysis carried out with archeological sites from the aformentioned sector, corresponding to two different temporal blocks (modified after Ozán and Pallo, 2019).

Hence, the Lago Argentino area seems to show a more complex mosaic-like landscape around 1000 CE, due to the presence of those (local?) wet conditions and the other generalized records of dry and/or warm signals observed from 51° to 52°39′ S (ID 32–37; Figure 8).

This more homogeneous environmental response to a dry climatic anomaly in the southernmost region of Patagonia (Figure 8) could respond to the lower altitude of the Andes at this latitude and the influence of the SAM on the precipitation pattern (Section 1.2). Indeed, between ca. 800 and 1300 CE, changes in human mobility likely related to the habitat fragmentation caused by the MCA aridity were postulated (Figure 7e) (Barberena, 2008). This preliminary observation was later supported by an increase of human occupations in interior spaces between ca. 900 and 1030 CE, particularly around permanent water sources (Figure 8a, re-analysis after Pallo and Ozán, 2014). Dry and warm conditions ascribed to the MCA at Laguna Azul, between ca. 800 and 1000 CE (Zolitschka et al., 2019; ID 36, grass steppe), and a less accurate arid anomaly registered at Laguna Potrok Aike between ca. 850 and 1400 CE (e.g. Haberzettl et al., 2005; ID 35, grass steppe), provide a paleoclimatic and chronological framework likely substantiating causal relations between the MCA and changes in human occupations for this southernmost sector of continental Patagonia.

The idea of spatially-even MCA “epic droughts” (e.g. Goñi et al., 2019; Stine, 1994) does not fit well with the evidence of northern steppes of the Isla Grande de Tierra del Fuego either. Here (Figure 7f), three robust environmental signals are associated with the MCA: warm conditions in the Marcelo Arévalo record (after Schimpf et al., 2011; ID 37, ca. 750–1150 CE, moorland), a wet signal inferred from the Karukinka record (van Bellen et al., 2016; this work; ID 38, ca. 750–1150 CE, deciduous forest-grass steppe ecotone), and warm conditions derived from the MD07-3132 record (Aracena et al., 2015; this work; ID 39, ca. 950–1200 CE). Beyond these anomalies related to the MCA, wet and warm conditions seem to predominate in the northern Island, particularly from ca. 950 CE (ID 37, 38, 39, 40, 41; Figure 8). In this context, a moderate decrease in the intensity of human occupations was registered between ca. 900 and 1150 CE (interpreted as an increase in the residential mobility or people relocation), along with an abandonment of the coasts of the Magellan Strait accompanied by a significant increase of occupations nucleated around the Atlantic coastline (Figure 8b and c; re-analysis after Ozán and Pallo, 2019; Pallo and Ozán, 2014). Warm conditions ascribed to the MCA could have affected marine productivity of the Magellan Strait due to a decreased upwelling and a consequently less intense human use of its coasts, whereas the preferential human use of Atlantic coasts could have been motivated by their more predictable and abundant resources (Borrero et al., 2008; Pallo and Ozán, 2014) under a landscape with high ecological contrasts.

Patagonian forests: Archeological silence and expectations. Figure 7 clearly shows that the region with the most abundant and robust records of the MCA, between 38° and 45° S (Figure 5), has not been subject to archeological discussions aiming to assess its impact on past human populations. This is likely due to the relatively low intensity of archeological research that arises from the poor archeological visibility and preservation in the forests (Barberena et al., 2015; Belardi et al., 2020; Méndez et al., 2016; Pallo et al., 2020; Scheinsohn and Matteucci, 2013; Scheinsohn et al., 2020). This picture may also suggest, however, that a dry/warm climatic anomaly in these humid and cold environments could have had a minor impact on resources consumed by hunter-gatherers. In other words, changes in specific proxy data resulting from climatic anomalies do not necessarily involve important changes at the level of forest landscape ecology. Since permanent water sources are abundant and ubiquitous in both Andean slopes, even under generalized arid conditions (either due to a precipitation decrease and/or an evapotranspiration increase), a very restricted impact in the resources consumed by humans is expected (i.e. *Hippocamelus bisulcus*, *Lama guanicoe*).

Nevertheless, by considering the large spatial range of highly mobile hunter-gatherers, and the fact that forested areas, near the steppe ecotone, were likely used by people from the eastern steppes (Borrero, 2004; Méndez et al., 2014; Scheinsohn et al., 2020), one could expect a more intense human signal in forests and ecotones during the MCA, particularly if eastern steppes also evidence arid conditions (Barberena et al., 2015). Nevertheless, the extrapolation of aridity inferred from forest records to the steppes should be treated with caution and analyzed on a case-by-case basis, bearing in mind latitudinal and microenvironmental factors (Sections 1.2 and 4, Figure 1).

Interestingly, systematic analyses of the MCA effect over human populations in the southern Fuegian forests (Figure 7g) did not yield clear results either (Fernández et al., 2020b; Ozán and Pallo, 2019), since some conspicuous changes observed in the human subsistence, technology, and use of space (e.g. Ozán and Pallo, 2019; Scheinsohn, 2010; Zangrando, 2009; Zangrando et al., 2016) occur a few centuries before the MCA local signal.

The problem of source, synchronicity, and causality in the human-environmental interplay. The interdisciplinary review presented here shows that the reconstruction of past human responses to the MCA in Patagonia is not straightforward. Several archeological hypotheses were built from current information reveals as inadequate sources of paleoenvironmental information, namely, archives located far away from the archeological case study or records with insufficient information to support the local effect of the MCA, in terms of interpretation robustness, chronological control or time range adequacy with the anomaly. In some other cases, human-environmental responses are not sustained since the synchronicity between social changes and the climatic anomaly cannot be specified.

Nevertheless, even for cases where a rather moderate synchronicity is observed, causality arises as the main issue. By broadly looking at the Late-Holocene archeology from Patagonia, several important changes in human trajectories, particularly concerning technology, subsistence, use of space, burial patterns, long-distance networks, and demography, took placed around 1000 CE (e.g. Campos and Castro Esnal, 2021; Flores Coni et al., 2021; García Guraieb et al., 2015; Gómez Otero et al., 2017; Ozán and Pallo, 2019; Zubimendi et al., 2015). Indeed, significant human changes were also registered in adjacent regions, north of Patagonia by this time (e.g. Barberena et al., 2018; Berón et al., 2021). An evaluation of georeferenced archeological radiocarbon dates from the whole of Patagonia indicates a continuous-Late-Holocene demographic increase reaching its maximum around 1000 CE, when new spaces were incorporated in the human mobility system (García Guraieb et al., 2019; Perez et al., 2016), as expected after an "effective occupation" phase (Borrero, 1994). Such demographic growth was also supported in the southernmost Fuego-Patagonia through age-at-death profiles (Suby et al., 2017). Thus, the supposed spatio-temporal scarcity of resources derived from the MCA aridity and its impact over different social spheres (e.g. subsistence, technology, mobility system, network interaction) could have also been amplified by this recorded demographic growth, which could even be the main trigger of the observed changes.

Final remarks

This study discussed the occurrence and characteristics of the MCA in Patagonia by systematically analyzing continuous paleoenvironmental archives. In this regard, a set of 48 paleoenvironmental records showing conspicuous environmentally changes around the MCA were compiled and ascribed to a particular climatic condition (Figures 2 and 3). A quality assessment concerning: (1) data interpretation robustness, (2) chronological control, and (3) time range adequacy to the MCA was applied on a case-by-case basis (Table 1, Sections 2 and 3). From the total cases ($N=48$) only 18 records fulfill the three quality criteria and are hence considered as robust evidence of the MCA in Patagonia (Table 2). According to this filtered body of evidence, dry and/or warm climatic anomalies might have characterized the MCA in Patagonia, between ca. 750 and 1350 CE, though with a core period around 900–1200 CE (Figure 7). Two exceptions that were also related to the MCA corresponding to wet signals (50° and 53° S) and are interpreted as local environmental responses.

Many other "consistent" climatic interpretations ($N=30$; Figure 6) not ascribed to the MCA due to chronological issues may suggest, however, the existence of resilient sectors and/or the low-magnitude impacts of the MCA in specific areas. The fact that extra-Andean Patagonian steppes present fewer paleoenvironmental studies than western forests and ecotones (and only one accurately related to the MCA), hampers the proper MCA characterization in this large phytogeographical unit. Nevertheless, even though the extra-Andean steppe does not yield a complete picture of the MCA environmental impact, all the archeological discussions about its effects on past hunter-gatherers are derived from the steppe archeology (Figure 7). This poses some limitations to the possibility of linking changes in human and environmental systems from Patagonia.

Particularly for the southern Patagonian steppes new insights arise from the integration of a wider paleoenvironmental background, since dry/warm conditions of the MCA seemed to have had uneven effects across the extra-Andean region. This fact is evidenced by many "consistent" climatic signals (not necessarily related to the MCA, but relevant for human biogeographical discussions) which indicate wet conditions partially overlapping with the MCA, between ~47°39′ and 50°40′ S, and then further to the south, in the Isla Grande de Tierra del Fuego (53°−55° S). On the other hand, a generalized aridity for southernmost continental Patagonia is observed between ~51° and 52°39′ S (Figure 8). Thus, during the MCA, a process of landscape fragmentation (Hobbs et al., 2008) might have taken place, though not exclusively produced by enhanced aridity in already semi-arid environments, but also because of the existence of sectors with wet anomalies (or "resilient patches") that might have accentuated ecological contrasts. This scenario shows a more complex MCA landscape than previously thought for southern Patagonia. Under these conditions, large-scale relocations and interactions of people coming from those "generalized" arid areas in southernmost Patagonia to the wet-dry mosaic recorded further north could be expected, given the fluid and wide social networks that these populations would have had (e.g. Belardi and Goñi, 2006; Borrero et al., 2011; Franco et al., 2018; see also Whallon, 2006). While available evidence is inconclusive in this regard, these distant records may indicate the need to zoom out in the analysis of the impact of the MCA on human societies from Patagonia, where given archeological changes recorded at regions devoid of local dry anomalies may reflect human responses to climatic changes in distant regions. Conversely, whereas Patagonian forests present the most abundant and accurate evidence of the MCA, no systematic archeological discussions have been developed. This could be likely related to the fact that significant changes observed in proxy data might have not necessarily involved important environmental changes. In this sense, it is fair to suggest that the impact of MCA arid anomalies on hunter gatherers societies in Patagonia is only visible in some parts of the dry Patagonian steppes.

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Supplemental material

Supplemental material for this article is available online.

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