Out of Amazonia: late-Holocene climate change and the Tupi–Guarani trans-continental expansion

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Abstract

The late Holocene expansion of the Tupi-Guarani languages from southern Amazonia to SE South America constitutes one of the largest expansions of any linguistic family in the world, spanning ~ 4000 km between latitudes 0°S and 35°S at about 2500 yr B.P. However, the underlying reasons for this expansion are a matter of debate. Here, we compare continental-scale palaeoecological, palaeoclimate, and archaeological datasets, to examine the role of climate change in facilitating the expansion of this forest-farming culture. Because this expansion lies within the path of the South American Low-Level Jet, the key mechanism for moisture transport across lowland South America, we were able to explore the relationship between climate change, forest expansion, and the Tupi-Guarani. Our data synthesis shows broad synchrony between late Holocene increasing precipitation and southerly expansion of both tropical forest and Guarani archaeological sites – the southernmost branch of the Tupi-Guarani. We conclude that climate change likely facilitated the agricultural expansion of the Guarani forest-farming culture by increasing the area of forested landscape that they could exploit, showing a prime example of ecological opportunism.

Keywords: paleoalaeoclimate; Late Holocene climate change; human ecology; language expansion; Amazonia; Tupi-Guarani

INTRODUCTION

The expansion of farmers and their languages is arguably one of the most important processes that took place during Holocene human history (Ammerman and Cavalli-Sforza, 2014; Anthony, 2009; Kirch, 2000; Bellwood and Renfrew, 2002). This process brought significant changes in technologies and social and political structures, as well as novel landscape management practices to the new regions that were colonised. Across the globe, several cultural expansions have been associated with climate change, whereby climate exerted a control on the extent of landscapes favoured by particular cultural groups (e.g., Büntgen et al., 2016; Kuper and Kröpelin, 2006). For example, the drought-induced reduction in forest cover and the emergence of savanna corridors during the middle Holocene enabled the Bantu to colonise what was once dense forest of the Congo and other regions of Africa (Grollemund et al., 2015; Oslisly et al., 2013). In central Asia, the horse-riding Scythian people capitalised on the transformation of hostile desert into steppe, brought about by higher rainfall in the last millennium B.C. (van Geel et al., 2004). Similarly, the onset of more humid conditions in the central Eurasian steppes in the 13th century A.D. appears to have triggered the expansion of the largest contiguous land empire in world history, the Mongol empire (Pederson et al., 2014).

Similar to the Arawak expansion (Heckenberger, 2002), the Tupi-Guarani is one of the largest expansion of an ancient people in lowland South America spreading across 4,000 kilometres and stretching from southwestern (SW) Amazonia to the subtropical Atlantic coast of southeast (SE) South America. The cause of this mass human expansion remains a debated topic in New World archaeology, bioarchaeology, genetics and linguistics (Heckenberger et al., 1998; Noelli, 1998; Neves, 2011; Neves et al., 2011; Marrero et al., 2007; Walker et al., 2012; Rodrigues and Cabral, 2012; Eriksen and Galucio, 2014; Brochado, 1989; Miller, 2009). Similar to other cases of language spread with farmers' demic diffusion (Diamond and Bellwood, 2003), the explanation for the Tupi-Guarani dispersal out of Amazonia has been demographic growth propelled by agriculture, coupled with a strong territoriality, long-range political networks, and an expansionist warlike ideology (Noelli, 1998; Brochado, 1989). However, an explanation relying solely on socio-political and economic causes fails to account for either the timing or route of the Tupi-Guarani expansion (Scheel-Ybert et al., 2014). Early attempts to link climate change with the expansion of the Tupi-Guarani are based on limited and now outdated palaeoecological reconstructions. Drawing on refuge theory (Haffer, 1974; Prance, 1982) and the available palaeoecological records (e.g., Absy, 1979; Ab'Saber, 1977), Meggers (1982) and Miggliaza (1982) suggest that the Tupi-Guarani expansion out of SW Amazonia was a response to the onset of drier climatic episodes that reduced the forest around 2000 yr BP forcing Tupi-Guarani groups to migrate to other regions. This scheme was followed by several Brazilian archaeologists (e.g., Schmitz, 1991) in their interpretation of Tupi-Guarani migrations. In a recent review of palaeoecological data, Neves (2013) called the attention to the correlation between a trend of increasing humidity around 3500 yr B.P. and the spread of economic strategies traditionally denominated the 'tropical forest pattern' across the whole Amazon. Neves (2013) suggests that the climate changes that took between the mid and late Holocene likely 'triggered a stronger reliance on these diverse agroforestry systems and the establishment of large sedentary settlements across the area'. However, this study restricted to Amazonia did not link the increased climatic humid conditions with the migration of populations either within or outside of Amazonia. More recently, Bonomo et al. (2015) carried out the latest synthesis of the nature and pace of the Guarani expansion SE South America. Based on a couple of geomorphological studies (Iriondo and Garcia, 1993; Stevaux, 2000), these authors played down the role of climate in the expansion of the Guarani in SE South America by stating that 'The climatic oscillations during this period do not appear to have a strong influence on the identified pulses of Guarani expansion, which transcends dry, warm, and humid moments'. Furthermore, they do not connect the expansion of the Guarani in the Rio de la Plata basin to their SW Amazonia homeland.

Despite the relative wealth of palaeoclimate, palaeoecological and archaeological data from this region of lowland South America that have accumulated during the last three decades, until now, the relationship between the expansion of this linguistic family of forest farmers and climate change out of Amazonia has not been adequately explored in the light of recent data. As a result, although the fine-scale pattern of the Tupi-Guarani settlement in SE South America is coming into sharper focus (Bonomo et al., 2015), the potential role of climate change as the root cause of the continental-scale Tupi-Guarani expansion has never been properly evaluated.

MATERIALS AND METHODS

To assess the role of climate in the expansion of the Tupi-Guarani out of Amazonia, we have marshalled archaeological, palaeoclimate, and palaeoecological datasets to test our hypothesis that increasing late Holocene precipitation drove forest expansion, which in turn facilitated the expansion of the Tupi-Guarani culture from SW Amazonia across SE South America. We do this by synthesizing data from 197 dated archaeological sites from the

Guarani, who represent the southernmost branch of the Tupi-Guarani family (Figure 1, Section S1, Tables S1 and S2, available online), 3 representative palaeo-precipitation records (Figure 1, Section S2, available online), and 73 palaeoecological records (Figure 1, Section S3, Tables S3-S6, available online). Because all these records lie within the path of the South American Low-Level Jet (SALLJ) (Figure S1, available online), the key mechanism for moisture transport across lowland South America, we are able to explore the relationship between climate change, forest expansion, and Guarani expansion.

RESULTS

Evidence for the Guarani expansion

The Tupían linguistic stock is one of the largest of lowland South America. It consists of around sixty languages grouped in ten linguistic families, of which the Tupi-Guarani family is the most widely dispersed – being the only one extending beyond Amazonia (Rodrigues and Cabral, 2012) (Figures S2 and S3, available online). At the time of European arrival (AD1492), Tupi-Guarani speakers numbered in the millions (Viveiros de Castro, 1992). In the La Plata Basin and the whole of the Brazilian Atlantic Coast, they occupied a riverine and coastal network spanning over 4,000 km, and Tupi-Guarani-based *lingua francas* were still widely used in Brazil as recently as the 18th century (Noelli, 1998; Walker et al., 2012).

In SE South America, the historically recorded Tupi-Guarani groups were organized in regional chiefdoms constituted by confederacies of villages under the influence of a prominent political or spiritual leader (Noelli, 1998; Milheira and DeBlasis, 2014). War expeditions travelled hundreds of kilometres through major waterways to attack enemies, conquer territories, capture women, and, in some cases, enslave the defeated (Brochado, 1989; Santos-Granero, 2009). The strong bellicose ethos and predatory cosmology of the Tupi-Guarani included anthropophagic ritual feasting, which had a large social significance as a means of status acquisition until colonial times (Viveiros de Castro, 1992; Brochado, 1989; Milheira and DeBlasis, 2014; Fausto, 2012). Unlike other Amazonian language expansions that appear to have spread through trade and a pacific ethos (e.g. Arawak), historical Tupi-Guarani groups have long been perceived as inclined towards expansion and conquest (Hornborg et al., 2005).

The Tupi-Guarani lived in large palisaded villages, with almost all archaeological sites situated in forests close to navigable rivers (Scheel-Ybert et al., 2014). Management of forests was a key component of the Tupi-Guarani economy, including the introduction of plants to prepare the environment before their definitive annexation of a newly settled area (Noelli, 1998). They practised agroforestry polyculture, complemented with fishing, hunting and gathering (Noelli, 1998; Scheel-Ybert et al., 2014) and their expansion marks the widespread adoption of agriculture in SE South America, bringing with them 24 varieties of manioc (*Manihot esculenta*), 13 varieties of maize (*Zea mays*), 15 varieties of beans (*Phaseolus vulgaris*), and 21 varieties of sweet potato (*Ipomoea batatas*), among many other cultivated plants (Noelli, 1993; Brochado, 2001). Linguistic evidence indicating the presence of reflexes of the same name for 'cultivated patch of land' in nine of the ten linguistic families of the Tupi stock suggest that the speakers of the Proto-Tupi language practised agriculture reinforcing the idea that this was an agricultural expansion (Rodrigues, 2010). This argument is further strengthen by the presence of similar names for agricultural tools such as digging stick and axe, as well as major crops including manioc, sweet potato and yams in nearly all linguistic families of the stock (Rodrigues, 2010).

Despite the paucity of archaeological data in SW Amazonia (Macario et al., 2009), this region is considered to be the centre of origin of the Tupían stock, based upon linguistic (Rodrigues and Cabral, 2012; Walker et al., 2012; Miller, 2009), cranial morphological (Neves et al., 2011; Hubbe et al., 2014) and genetic data (Marrero et al., 2007; Santos et al., 2015). Five of the ten families of the Tupían stock are restricted to the modern state of Rondônia, Brazil (Eriksen and Galucio, 2014). It has long been recognised that such depth of ethnolinguistic diversity points to SW Amazonia as the homeland of the Tupían stock (Walker et al., 2012; Rodrigues and Cabral, 2012; Eriksen and Galucio, 2014). Linguists estimate that the Tupían stock initially split between 5-3 k yr BP, after which the Tupi-Guarani family split around 3-2 k yr BP (Walker et al., 2012; Rodrigues and Cabral, 2012; Miggliazza, 1982). Similarly, genetic data supports SW Amazonia as the purported place of origin of the Tupían groups (Marrero et al., 2007; Santos et al., 2015). Analyses of variability in autosomal and uniparental (Y-chromosome and mtDNA) genetic markers shows agreement with the linguistic models, evidencing an early expansion from the Madeira-Guaporé basin and a later continent-wide population spread associated with the Tupi-Guarani(Santos et al., 2015) ca. 2.8 k yr BP (Amorim et al., 2013). Cranial morphological data also demonstrate that individuals from Tupi-Guarani archaeological contexts in SE South America are grouped more closely with the Amazonian series than with the local populations (Neves et al., 2011).

Archaeologically, the expansion of Tupi-Guarani groups throughout eastern lowland South America coincides with the distribution of polychrome pottery, which is very distinctive from local traditions, but has prototypes in Amazonia (Brochado, 1989; Bonomo et al., 2015; Noelli, 1998). In spite of their expansion over thousands of kilometres, Tupi-Guarani sites show remarkably homogeneous material culture and settlement patterns characterised by the occurrence of anthropogenic dark earth located along major waterways associated with riverine forests (Bonomo et al., 2015; Scheel-Ybert et al., 2014). In historical times, Tupi-Guarani groups of SE South America were superb canoe navigators, which eased their dispersal along major waterways (Brochado, 1989).

Central Amazonia was initially thought to be the cradle of polychrome ceramics (Brochado, 1989), but recent archaeological data show that polychrome ceramics are a recent dispersal in that area, and too late to be related to the Tupi-Guarani expansion (Heckenberger et al., 1998). The Upper Madeira, SW Amazonia, is presently the area with the earliest polychrome ceramics and anthropogenic dark earths (Neves, 2011), with dates of 5 to 3 k yr B.P. for ceramic sites in this region (Table S1, available online), coinciding with the glottochronological estimates for the initial split of the Tupían stock. Beyond Amazonia, ceramics recognisable as Tupi-Guarani appear from 3 to 2 k yr B.P. (Macario et al., 2009; Bonomo et al., 2015; Noelli, 1998; Brochado, 1989) (Table S2, available online), in agreement with linguistic estimates.

This expansion took place at a time of widespread cultural change toward increasingly complex societies and the spreading of linguistic families across lowland tropical South America, including the Arawak (Heckenberger, 2002; Clement et al., 2015) and the Jê (Noelli, 2005). This is also a time when lowland societies began to transform the landscape at a scale not seen before. Extensive agricultural landscapes, such as raised-field systems in seasonally flooded savannas, began to be built from French Guiana to the *Llanos de Moxos* in Bolivia, while Amazonian Dark Earths, possibly associated with sedentism and intensive agriculture, appeared mainly along the bluffs of major rivers in Amazonia (Heckenberger and Neves, 2009; Neves, 2011; Arroyo-Kalin, 2010).

It is clear that, despite the lack of crucial archaeological data in the Upper Guapore River and the *Cerrado* connecting SW Amazonia to SE South America, current linguistic, genetic, cranial morphological and available archaeological data suggest that the Tupi-Guarani family split and began to spread southwards from Amazonia to SE South America (Figures 1 and 2) by about 3-2 k yr B.P. (Rodrigues and Cabral, 2012; Bonomo et al., 2015; Noelli, 1998). The archaeological data (Figures 1 and 4C) show that the Tupi-Guarani expanded beyond the 'mosaic zone' (Bellwood and Renfrew, 2002) of SW Amazonia to reach the 'spread zone' (Figure S2, available online) of this linguistic family in SE South America by about 2.5 k yr B.P., giving rise to the Guarani Tradition south of the 17°S parallel (Noelli, 1998; Bonomo et al., 2015).

Routes of expansion

Unlike their ancestors, who occupied interfluvial areas, the expansion of the Guarani out of Amazonia exclusively followed major rivers. Regardless of debates about the specific routes taken by the various Tupi-Guarani groups in their expansion throughout South America, there is general agreement that the upper Paraguay and Paraná rivers served as the main waterway routes for the southward spread of the Guarani from their homeland in SW Amazonia (Noelli, 1998; Brochado, 1989). The most widely accepted riverine route for the southward expansion of the TupiGuarani passes through the Upper Madeira-Guaporé river, bordering the *Llanos de Moxos*, to reach the Upper Paraguay river in the vicinty of the Pantanal wetland, from where the Guarani could spread, via major fluvial courses, to the whole La Plata Basin and the adjacent coast (Brochado, 1989; Noelli, 1998). This proposed route is supported by the proximity of the Guarani to languages of Bolivia (e.g., Guarayu and Siriono) (Brochado, 1989; Noelli, 1998) and because Guarani archaeological ceramics include forms and decorations (conical corrugated jars) acquired from eastern Bolivian traditions (Brochado, 1989). Unfortunately, although several Guarani sites have been documented in the Upper and Middle Paraguay river, they have not yet been dated (Bonomo et al., 2015) and at present the Upper Paraná holds the earliest dates. Future research in the region between the western border of the Pantanal and the Upper Guaporé will be crucial to fill the gap between the Tupían homeland in SW Amazonia and the beginning of the Guarani tradition in the Upper Paraguay river (Noelli, 1998).

Riverine gallery forests of the *Llanos de Moxos* savanna wetland and the *Gran Chaco* scrub may have also served as key routes of expansion for the Guarani out of Amazonia towards the Paraguay-Paraná system. Like the Amazon River system, the La Plata Basin comprises a network of huge rivers that constituted a major avenue for communication among different pre-Columbian groups that had watercraft. There are no important geographical barriers that separate these two large river systems. Therefore, the annual inundation of the *Llanos de Moxos* and Pantanal basins merges the watersheds of the Rio Madeira and the Rio Paraguay into a vast "freshwater sea", opening up a network of waterways extending far south to the Rio de la Plata estuary.

Another potential route of expansion may have been via the *Cerrado*. One might expect that the extensive *Cerrado* (savanna) biome of south-central Brazil (covering ca. 2,000,000 km^2), which separates the Amazonian and Atlantic forest biomes (Figures 1 and 2), would present a major environmental barrier to the Guarani culture reaching the Atlantic Forest biome of SE Brazil. However, when considered at finer spatial scales, the *Cerrado* biome is not a uniform expanse of savanna, but instead a highly heterogeneous forest-savanna mosaic. The savanna is confined to highly infertile soils and is interspersed with islands of semi-deciduous tropical forest on mesotrophic soils and extensive ribbons of riverine gallery forest which connect with both Amazonian and Atlantic Forest biomes. More recenlty, Almeida and Neves (2015) has hypothesised an eastern Amazonian origin for the Tupi-Guarani, however, the Tupi-Guarani dates in eastern Amazonian are contemporaneous with the Guarani dates on the Upper Parana, therefore, neglicting this hypothesis until more research is carried out. Last but not least, we should not discard the possibility that a few founder populations ‘leapfrog’ (sensu Fiedel and Anthony, 2003) from SW Amazonia to the Atlantic Forest, where they found the perfect niche and started their expansion from there. This hypothesis is supported by the relatively early chronology of the the Morro Grande site in Rio de Janeiro state, which belongs to the Tupinamba Tradition and dates back to around 2920 yr B.P. (Macario et al., 2009; Scheel-Ybert et al., 2008). The probability that this initial long-distance leap may also have been followed by later subsequent expansion episodes from this region as forest expanded across SE South America should also be taken as a testable hypothesis for future studies. However, at the moment, this argument left unexplained how the earliest Guarani sites appear in the Upper Parana River and not in the Atlantic forest as this scenario would predict.

Regardless of the particular mechanism or route they took, once they arrived in the upper La Plata basin, several waves of expansion of the Guarani across SE South America can be clearly identified with current data: (i) *ca*. 2.5 to 2 k yr B.P., onset of colonization of the Upper Paraná river; (ii) *ca*. 2 to 1.5 k yr B.P., settlement along the Uruguay river; (iii) *ca*. 1.5 to 1 k yr B.P., onset of colonization of the Southern Brazilian coast; and (iv) after *ca.* 1 k yr B.P., establishment of the southernmost Guarani settlements in the Paraná Delta (Bonomo et al., 2015) (Figures 1 and 2, Movie S1, available online). This expansion conforms to a dendritic pattern, whereby the first settlements in a newly colonised area always occurred along major forested waterways. It was only after the occupation of these preferred environments had been consolidated that colonization of small tributaries ensued (Bonomo et al., 2015). The southward movement from Amazonia across SE South America represents a process of expansion, rather than migration, because daughter villages branched out of over-populated parent villages while maintaining interaction and social ties with them, so that old territories were never abandoned. This process resulted in an expanding radius of village networks through gradual population waves following the major forested river courses (Noelli, 1998). It has been well-documented in the Pardo river valley, Rio Grande do Sul, where it has been clearly shown that the earliest and larger sites occupy the fertile floodplain, whereas the latest sites are smaller and located in higher elevations (Rogge, 2005).

Evidence for climate-driven forest expansion in the Holocene

Most of the rainfall in the southern hemisphere tropics of South America is seasonal and monsoonal in character. During the austral summer, the SALLJ (Zhou and Lau, 1998) transports moisture generated by deep convection in the core of the Amazon basin south-westwards towards the foothills of the Andes. From here, it is deflected along the eastern flank of the Bolivian Andes along a diagonal path towards southern Brazil, where it exits the continent at the South Atlantic convergence zone (Figure S1, available online).

Palaeoclimate records in the regions influenced by the SALLJ – Lake Titicaca (the Altiplano) (Baker et al., 2001), Laguna La Gaiba (the central lowlands) (Whitney and Mayle, 2012), and Botuverá cave (southern Brazil) (Cruz et al., 2005) – all demonstrate a consistent long-term trend of increasing precipitation from the mid-Holocene (~ 6 k yr B.P.) toward the present (Figure 4A, Section S2, available online). This trend has been attributed to a progressive strengthening of the monsoon over this period as orbital forcing (precession cycle) increases austral summer insolation (Figure S1, available online) (Berger and Loutre, 1991). Modelled rainfall from Hadley Centre climate model (HadCM3) simulations covering the last 6 k yr (Section S2 and Figure S5, available online) is in line with these palaeoclimate reconstructions and demonstrates that the palaeoclimate proxy data reflect climate change across our study area as a whole. Our palaeovegetation data syntheses (Figure 4B) show that, despite some variability in the spatio-temporal pattern of forest dynamics among sites – due to a range of factors, such as the diversity of vegetation types (Figure 1), distance from an ecotone (Mayle et al., 2000), pollen catchment size (Carson et al., 2014), geomorphology, edaphic conditions, degree of human impact (Carson et al., 2014) – the proportion of sites with a forest-dominated catchment increases consistently through the mid-late Holocene, between around 5 and 1 k yr B.P. (Figures 2, 3 and 4B, Movie S1, available online). This is exemplified by: (i) the expansion of the southern Amazon rainforest margin (Mayle et al., 2000; Carson et al., 2014; Flantua et al., 2015); (ii) expansion of seasonally-dry tropical forest margins in the Chiquitanía region of lowland Bolivia and at the southern margin of the *Cerrado* (savanna) biome (Ledru, 1993; Oliveira-Filho and Ratter, 1995); (iii) the development of dry forest in the *Misiones* region of southern Brazil (Zech et al., 2009); and (iv) the development and expansion of *Araucaria* forests in the southern Brazilian highlands (Behling and Pillar, 2007). This temporal pattern of forest expansion follows the trend of increasing rainfall through the mid-late Holocene, pointing to a causal relationship (Figures 2 and 3). We infer that progressive strengthening of the austral summer monsoon (and consequent reduction in length/severity of the dry season) over this period enabled forest expansion at the expense of more drought-tolerant savanna/grassland ecosystems.

DISCUSION

The period of climate-driven forest expansion in SW Amazonia and SE South America (*ca*. 5 – 1 k yr B.P.) encompasses the period of Tupi-Guarani expansion (~ 2.5 – 1 k yr B.P.) across this region (figures 2 and 3). High quality palaeoclimate data from Lake Titicaca can be considered as a 'rain gauge' for SW Amazonia because most of the precipitation reaching this high Andean site is derived from advected Amazonian moisture delivered via the SALLJ. Progressive strengthening of the monsoon and increased moisture delivery via the SALLJ caused lake level to rise by 90 m from its 6 k yr B.P. lowstand to reach near-modern levels by 3 k yr B.P. (Figure 4A, Figure S5, available online). By 2.5 k yr B.P., climate-driven rainforest expansion in SW Amazonia (Mayle et al., 2000) may have been sufficient to facilitate the initial wave of expansion of the Tupi-Guarani out of Amazonia.

It is likely that rising precipitation through the mid-late Holocene (Figure 4A, Figure S5, available online) would have increased river levels (making them even more navigable by the Guarani culture) which in turn would have led to expansion of gallery forests within which new Tupi-Guarani villages could be established. Subsequent waves of Guarani expansion from 2 k yr B.P. until European Conquest (0.5 k yr B.P.) occur in phase with continued climate-driven forest expansion (Figure 3, Figure S5 and Movie S1, available online).

A comparison of the time of first increase in vegetation score and the age of the archaeological sites in SE South America clearly shows that forest expanded immediately before or concomitant with the arrival of the Guarani, within the limits of the chronological resolution of our data. The general trend shows that, as the forest expands southwards, the Guarani colonisation ensues. For example, in the middle Paranapanema (22°S), forest expansion begins around 4-3.5 k yr BP and vegetation fully converts to forest by 3-2.5 k yr BP (Figure 2). The Guarani arrival in the upper Paraná and later expansion to the Paranapanema soon follows at 2.5-2 k yr BP. Increases in vegetation score occur later as one progresses further south, dating to 2.5-2 k yr BP in the middle Paraná (27°S) (Figures 2 and 3). This trend is immediately accompanied by the Guarani expansion down the Paraná around 2-1.5 k yr BP. Finally, in the Ibicuí river (30°S), the first increase in vegetation score takes place at 1.5-1 k yr BP, preceding the southernmost movement of the Guarani towards the Paraná delta (35°S) at 1-0.5 k yr BP (Figure 3).

CONCLUSIONS

Although east-west migrations are in general more common than north-south movements because the former are less likely to encounter variation in climate and habitat (Diamond and Bellwood, 2003), the Guarani expansion from SW Amazonia to the Paraná River Delta constitutes a remarkable latitudinal shift. Arguably, it is the climatic link between these two end regions, created by the SALLJ (Figure S1), and expansion of the preferred Guarani environment (riverine forest) in a north-south direction, that allowed such a massive latitudinal expansion of the Guarani. The complex political organisation, long distance village network and bellicose ethos of the Guarani (Viveiros de Castro, 1992; Noelli, 1998) were socio-political factors that certainly played a significant, proximal role in the Guarani expansion, but our data analysis suggests that climate change may have been the root cause that triggered the Guarani expansion across the broad temporal (millennial) and spatial (sub-continental) scales of our study. Our findings show that, by increasing the area of forested landscape that the Guarani could exploit, the climate-driven forest expansion created an ecological opportunity that facilitated the expansion of the Guarani forest-farming culture over their preferred familiar landscape. Our results suggest that the most parsimonious explanation for the timing of Guarani expansion, ca. 3-2 k yr B.P., is the climate-driven forest expansion across southern hemisphere South America at this time.

Other tropical agriculturalists which underwent major expansion, such as the Bantu farmers in Africa, appear to have avoided rainforest, instead preferring savanna corridors and forest openings that were likely caused by a mid-late Holocene change to progressively drier climatic conditions (Grollemund et al., 2015; Oslisly et al., 2013). In contrast, the Guarani appear to have taken full advantage of climate-driven forest expansion to spread along the major rivers connecting southeastern South America with their ancestral homeland in SW Amazonia. Furthermore, the late Holocene expansion of seasonally dry forests south of the

Amazon likely eased Guarani spread because: (i) soils beneath seasonally dry forest are generally less weathered, and thus more fertile, than those of humid evergreen forests, and (ii) seasonally dry forests are easier to clear for agroforestry, the prolonged dry season enabling early farmers to efficiently clear vegetation and prepare plots for planting with the simple use of fire.

In conclusion, our results contrast with i) traditional hypothesis based on now outdated palaeoecological interpretations, which suggest that the reduction of forest during the purported dry period that took place around 2000 yr BP would have pushed the Tupi-Guarani farmers dependent on forest resources to migrate (Meggers, 1982; Miggliazza, 1982) and ii) recent reviews which downplay the role of climate in the expansion of the Guarani (Bonomo et al., 2015). On the contrary, they show that a more humid Late Holocene climate promoted the expansion of forest outside of Amazonia, which in turn, allowed the continental spread of the Amazon TupiGuarani rainforest farmers. Our interdisciplinary investigation shows that the interaction of socio-cultural and environmental factors has been important in shaping human dispersal across South America.

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References cited

Ab'Saber AN. (1977) Espaços ocupados pela expansão dos climas secos na América do Sul, por ocasião dos períodos glaciales quaternários. *Paleoclimas (Sao Paulo)* 3.
Absy ML. (1979) A palynological study of Holocene sediments in the Amazon basin. Amsterdam: University of Amsterdam.
Almeida FO and Neves E. (2015) Evidências arqueológicas para a origem dos Tupi-Guarani no leste da Amazônia. *Mana* 21: 499-525.
Ammerman AJ and Cavalli-Sforza LL. (2014) *The Neolithic transition and the genetics of populations in Europe*: Princeton University Press.
Amorim CEG, Bisso-Machado R, Ramallo V, et al. (2013) A Bayesian approach to genome/linguistic relationships in native south americans.
Anthony DW. (2009) *The horse, the wheel, and language: how Bronze-Age riders from the Eurasian steppes shaped the modern world*: Princeton University Press.
Arroyo-Kalin M. (2010) The Amazonian formative: crop domestication and anthropogenic soils. *Diversity* 2: 473-504.
Baker PA, Seltzer GO, Fritz SC, et al. (2001) The history of South American tropical precipitation for the past 25,000 years. *Science* 291: 640.
Behling H and Pillar VDP. (2007) Late Quaternary vegetation, biodiversity and fire dynamics on the southern Brazilian highland and their implication for conservation and management of modern Araucaria forest and grassland ecosystems. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362: 243-251.
Bellwood P and Renfrew C. (2002) *Examining the farming/language dispersal hypothesis*: Cambridge: McDonald Institute for Archaeological Research.
Berger A and Loutre M-F. (1991) Insolation values for the climate of the last 10 million years. *Quaternary Science Reviews* 10: 297-317.
Bonomo M, Angrizani RC, Apolinaire E, et al. (2015) A model for the Guaraní expansion in the La Plata Basin and littoral zone of southern Brazil. *Quaternary International* 356: 54-73.
Brochado JP. (1989) A expansão dos Tupi e da cerâmica da tradição policrômica amazônica. *Dédalo (São Paulo)*: 65-82.
Brochado JP. (2001) Tupi. *Encyclopedia of Prehistory.* Springer, 343-354.
Büntgen U, Myglan VS, Ljungqvist FC, et al. (2016) Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience* 9: 231-236.
Carson JF, Whitney BS, Mayle FE, et al. (2014) Environmental impact of geometric earthwork construction in pre-Columbian Amazonia. *Proceedings of the National Academy of Sciences* 111: 10497-10502.
Clement CR, Denevan WM, Heckenberger MJ, et al. (2015) The domestication of Amazonia before European conquest. *Proceedings of the Royal Society of London B: Biological Sciences* 282.
Cruz FW, Burns SJ, Karmann I, et al. (2005) Insolation-driven changes in atmospheric circulation over the past 116,000 years in subtropical Brazil. *Nature* 434: 63-66.
Diamond J and Bellwood P. (2003) Farmers and their languages: the first expansions. *Science* 300: 597-603.
Eriksen L and Galucio AV. (2014) The Tupian expansion. In: O'Connor L and Muysken P (eds) *The Native Languages of South America: Origins, Development, Typology.* Cambridge University Press, 177-199.
Fausto C. (2012) *Warfare and Shamanism in Amazonia*: Cambridge University Press.

Fiedel SJ and Anthony DW. (2003) Deerslayers, pathfinders, and icemen: origins of the European Neolithic as seen from the frontier. In: Rockman M and Steele J (eds) *The colonization of unfamiliar landscapes: The archaeology of adaptation.* London: Routledge, 144-168.

Flantua S, Hooghiemstra H, Vuillle M, et al. (2015) Climate variability and human impact on the environment in South America during the last 2000 years: synthesis and perspectives. *Climate of the Past Discussions* 11: 3475-3565.

Grollemund R, Branford S, Bostoen K, et al. (2015) Bantu expansion shows that habitat alters the route and pace of human dispersals. *Proceedings of the National Academy of Sciences* 112: 13296-13301.

Haffer J. (1974) *Avian Speciation in Tropical South America,* Massachusetts: Nuttall Ornithological Club Publications.

Heckenberger M. (2002) Rethinking the Arawakan diaspora: hierarchy, regionality, and the Amazonian formative. In: Hill JD and Santos-Granero F (eds) *Comparative Arawakan histories: rethinking language family and culture area in Amazonia.* Urbana: University of Illinois Press, 99-122.

Heckenberger M and Neves EG. (2009) Amazonian archaeology. *Annu Rev Anthropol* 38: 251-266.

Heckenberger MJ, Neves EG and Petersen JB. (1998) De onde surgem os modelos? As origens e expansões Tupi na Amazônia Central. *Revista de Antropologia* 41: 69-96.

Hornborg A, Gassn R, Heckenberger M, et al. (2005) Ethnogenesis, regional integration, and ecology in prehistoric Amazonia: toward a system perspective 1. *Current Anthropology* 46: 589-620.

Hubbe M, Okumura M, Bernardo DV, et al. (2014) Cranial morphological diversity of early, middle, and late Holocene Brazilian groups: Implications for human dispersion in Brazil. *American journal of physical anthropology* 155: 546-558.

Iriondo MH and Garcia NO. (1993) Climatic variations in the Argentine plains during the last 18,000 years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 101: 209-220.

Kirch PV. (2000) *On the road of the winds: an archaeological history of the Pacific Islands before European contact*: University of California Press.

Kuper R and Kröpelin S. (2006) Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution. *Science* 313: 803-807.

Ledru M-P. (1993) Late Quaternary environmental and climatic changes in central Brazil. *Quaternary Research* 39: 90-98.

Macario K, Buarque A, Scheel-Ybert R, et al. (2009) The long-term Tupiguarani occupation in southeastern Brazil. *Radiocarbon* 51: 937.

Marrero AR, Silva-Junior WA, Bravi CM, et al. (2007) Demographic and evolutionary trajectories of the Guarani and Kaingang natives of Brazil. *American journal of physical anthropology* 132: 301-310.

Mayle FE, Burbridge R and Killeen TJ. (2000) Millennial-scale dynamics of southern Amazonian rain forests. *Science* 290: 2291-+.

Meggers BJ. (1982) In: Prance GT (ed) *Biological Diversification in the Tropics: Proceedings of the Fifth International Symposium of the Association for Tropical Biology.* New York Columbia University Press, 483-496.

Miggliazza E. (1982) In: Prance GT (ed) *Biological Diversification in the Tropics: Proceedings of the Fifth International Symposium of the Association for Tropical Biology.* New York: Columbia University Press, 497-519.

Milheira RG and DeBlasis P. (2014) Tupi-Guarani Archaeology in Brazil. *Encyclopedia of Global Archaeology.* Springer, 7384-7389.

Miller ET. (2009) A Cultura Cerâmica do Tronco Tupí no alto Ji-Paraná, Rondônia, Brasil: Algumas Reflexões Teóricas, Hipotéticas e Conclusivas. *Revista Brasileira de Linguística Antropológica* 1: 35-136.
Neves EG. (2011) Archaeological cultures and past identities in the pre-Colonial Central Amazon. In: Hornborg A and Hill JD (eds) *Ethnicity in Ancient Amazonia: Reconstructing Past Identities from Archaeology, Linguistics, and Ethnohistory.* Boulder: University of Colorado Press, 31-56.
Neves EG. (2013) Was agriculture a key productive activity in pre-colonial Amazonia? The stable productive basis for social equality in the Central Amazon. In: Brondizio ES and Moran EF (eds) *Human-Environment Interactions.* . Springer, 371-388.
Neves WA, Bernardo DV, Okumura M, et al. (2011) Origin and dispersion of the Tupiguarani: what does cranial morphology say? *Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas* 6: 95-122.
Noelli F. (1993) Sem Tekohá não há Tekó (Em Busca de um Modelo Etnoarqueológico da Aldeia e da Subsistência Guarani e sua Aplicação a uma Área de Domínio no Delta do Rio Jacuí - RS). *Department of History.* PUCRS, Porto Alegre.
Noelli F. (1998) The Tupi: explaining origin and expansions in terms of archaeology and of historical linguistics. *Antiquity* 277: 648-663.
Noelli FS. (2005) Rethinking stereotypes and the history of research on Jê populations in South Brazil: An interdisciplinary point of view. In: Funari P, Zarankin A and Stovel E (eds) *Global Archaeological Theory. Contextual Voices and Contemporary Thoughts.* New York: Springer, 167-190.
Oliveira-Filho Ad and Ratter J. (1995) A study of the origin of central Brazilian forests by the analysis of plant species distribution patterns. *Edinburgh Journal of Botany* 52: 141-194.
Oslisly R, White L, Bentaleb I, et al. (2013) Climatic and cultural changes in the west Congo Basin forests over the past 5000 years. *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 368: 20120304.
Pederson N, Hessl AE, Baatarbileg N, et al. (2014) Pluvials, droughts, the Mongol Empire, and modern Mongolia. *Proceedings of the National Academy of Sciences* 111: 4375-4379.
Prance G. (1982) *Biological diversification in the Tropics: Proceedings of the Fifth International Symposium of the Association for Tropical Biology,* New York: Columbian University Press.
Rodrigues A. (2010) Linguistic reconstruction of elements of prehistoric Tupí culture. In: Carlin EB and van de Kerke S (eds) *Linguistics and Archaeology in the Americas: The Historization of Language and Society.* Leiden: Brill, 1-10.
Rodrigues AD and Cabral AS. (2012) Tupían. In: Campbell L and Grondona V (eds) *The Indigenous Languages of South America.* Berlin/Boston: Mouton de Gruyter, 495-574.
Rogge JH. (2005) Fenômenos de fronteira: Um estudo das situações de contato entre os portadores das tradições cerâmicas pré-históricas no Rio Grande do Sul. *Pesquisas Antropologia* 62.
Rowe H, Dunbar R, Mucciarone D, et al. (2002) Insolation, Moisture Balance and Climate Change on the South American Altiplano Since the Last Glacial Maximum. *Climatic Change* 52: 175-199.
Santos-Granero F. (2009) *Vital Enemies. Slavery, Predation, and the Amerindian Political Economy of Life,* Austin: University of Texas Press.

Santos EJMd, Silva ALSd, Ewerton PD, et al. (2015) Origins and demographic dynamics of Tupí expansion: a genetic tale. *Boletim do Museu Paraense Emílio Goeldi. Ciências Humanas* 10: 217-228.
Scheel-Ybert R, Beauclair M and Buarque A. (2014) The forest people: landscape and firewood use in the Araruama region, southeastern Brazil, during the late Holocene. *Vegetation History and Archaeobotany* 23: 97-111.
Scheel-Ybert R, Macario K, Buarque A, et al. (2008) A new age to an old site: the earliest Tupiguarani settlement in Rio de Janeiro State? *Anais da Academia Brasileira de Ciências* 80: 763-770.
Schmitz PI. (1991) Migrantes da Amazonia: A Tradicao Tupiguarani. In: Kern A (ed) *Arqueologia Prehistorica do Rio Grande do Sul.* Porto Alegre: Mercado Aberto, 295-330.
Stevaux JC. (2000) Climatic events during the late Pleistocene and Holocene in the upper Parana River: Correlation with NE Argentina and South-Central Brazil. *Quaternary International* 72: 73-85.
van Geel B, Bokovenko N, Burova N, et al. (2004) Climate change and the expansion of the Scythian culture after 850 BC: a hypothesis. *Journal of Archaeological Science* 31: 1735-1742.
Viveiros de Castro EB. (1992) *From the Enemy's Point of View: humanity and divinity in an Amazonian society,* Chicago: University of Chicago Press.
Walker RS, Wichmann S, Mailund T, et al. (2012) Cultural phylogenetics of the Tupi language family in lowland South America. *PLoS One* 7: e35025.
Wang X, Auler AS, Edwards R, et al. (2007) Millennial-scale precipitation changes in southern Brazil over the past 90,000 years. *Geophysical Research Letters* 34.
Whitney BS and Mayle FE. (2012) Pediastrum species as potential indicators of lake-level change in tropical South America. *Journal of Paleolimnology* 47: 601-615.
Zech M, Zech R, Morrás H, et al. (2009) Late Quaternary environmental changes in Misiones, subtropical NE Argentina, deduced from multi-proxy geochemical analyses in a palaeosol-sediment sequence. *Quaternary International* 196: 121-136.
Zhou J and Lau K. (1998) Does a monsoon climate exist over South America? *Journal of Climate* 11: 1020-1040.

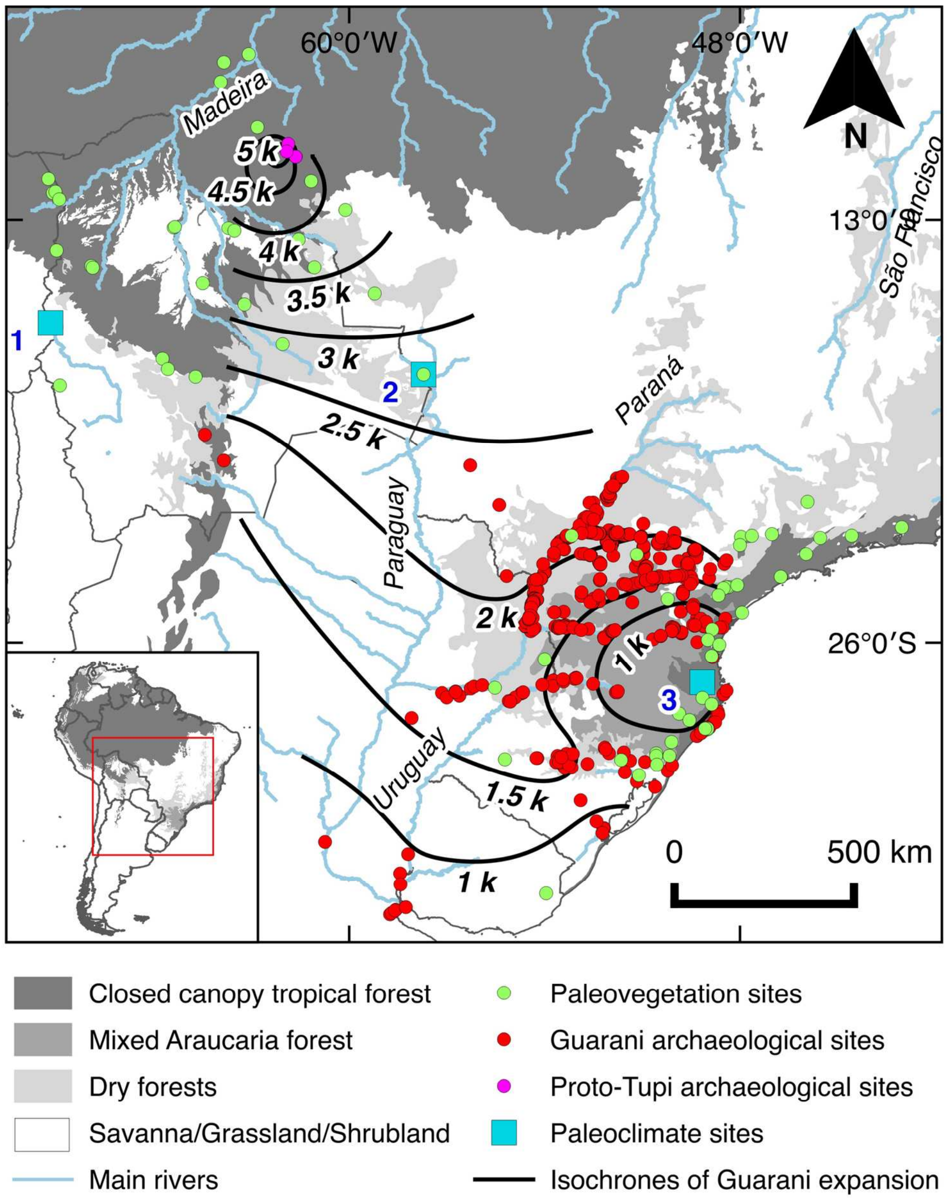

Figure 1. Map of study area showing locations of 1181 Guarani and Proto-Tupi archaeological sites (see Tables S1 and S2, available online), palaeoecological sites (see Table S6, available online) and palaeoclimate sites, including: 1. Lake Titicaca; 2. Laguna La Gaiba; and 3. Botuverá Cave (Section S2, available online). Isochrones show the time-transgressive movement of the Guarani culture (k = k yr B.P.).
144x183mm (300 x 300 DPI)

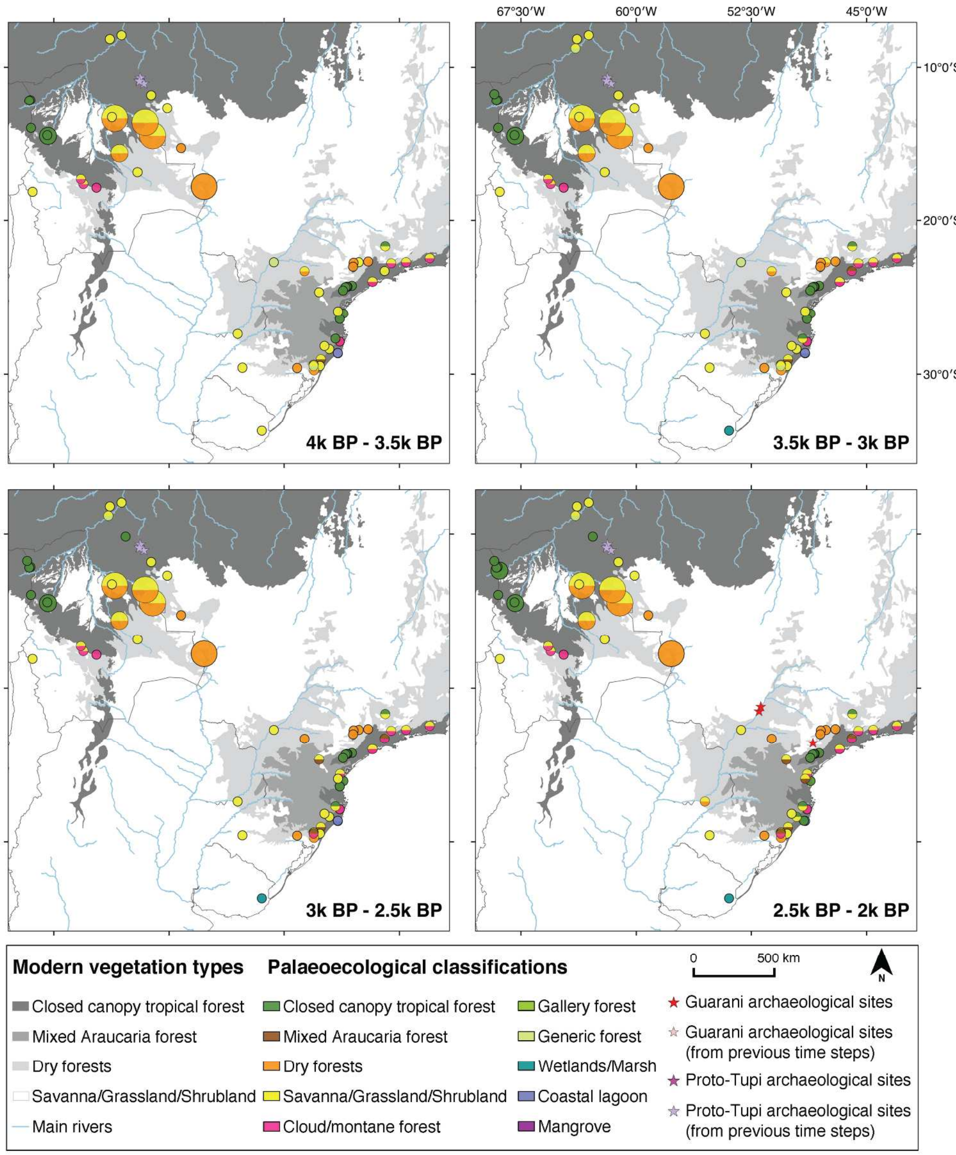

Figure 2. Archaeological and palaeoecological data at 0.5k yrs (500 year) time slices from 4 to 2 k yrs B.P. (see Sections S1 and S2 and Movie S1 for visualisation in motion, available online).
254x298mm (300 x 300 DPI)

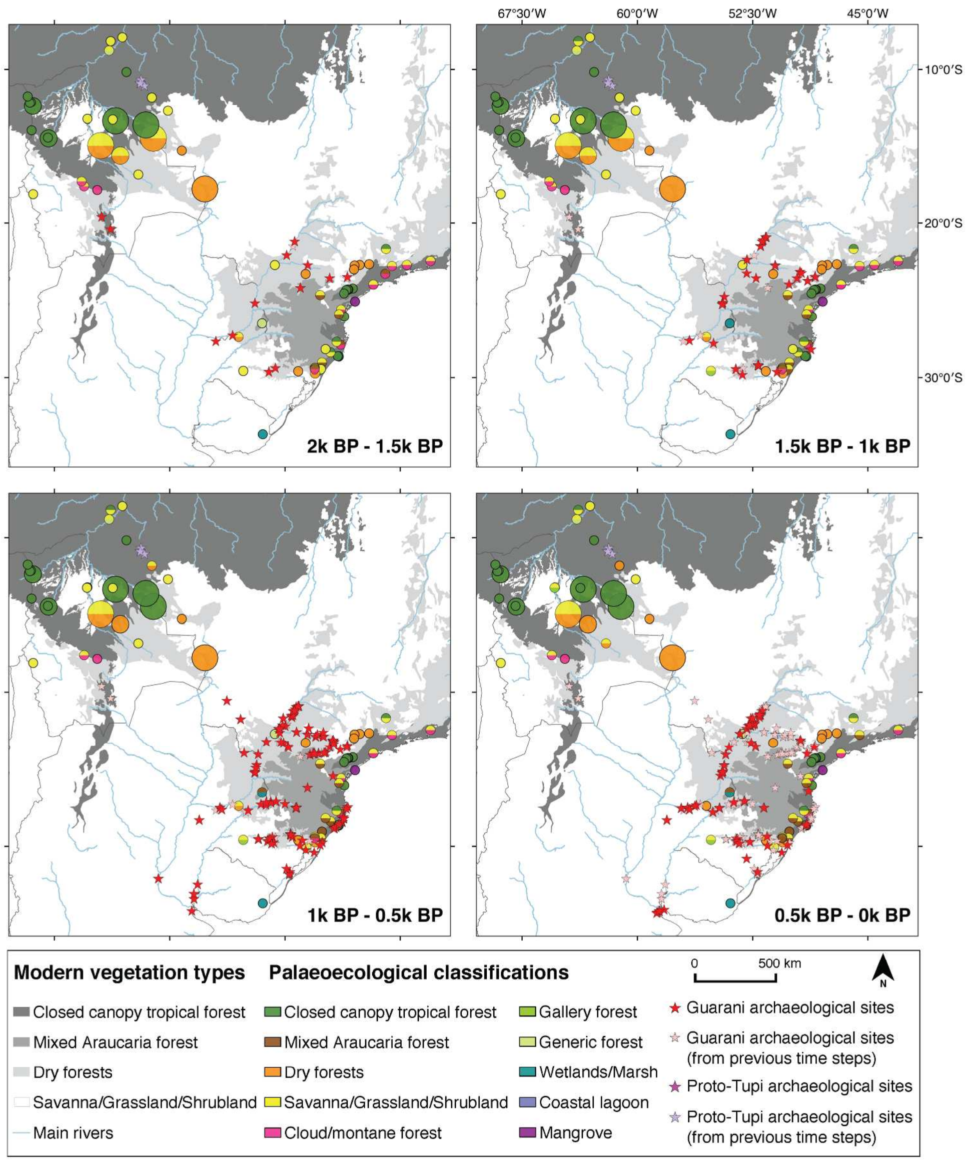

Figure 3. Archaeological and palaeoecological data at 0.5k yrs (500 year) time slices from 2k yrs B.P. to present (see Sections S1 and S2 and Movie S1 for visualisation in motion, available online).

254x298mm (300 x 300 DPI)

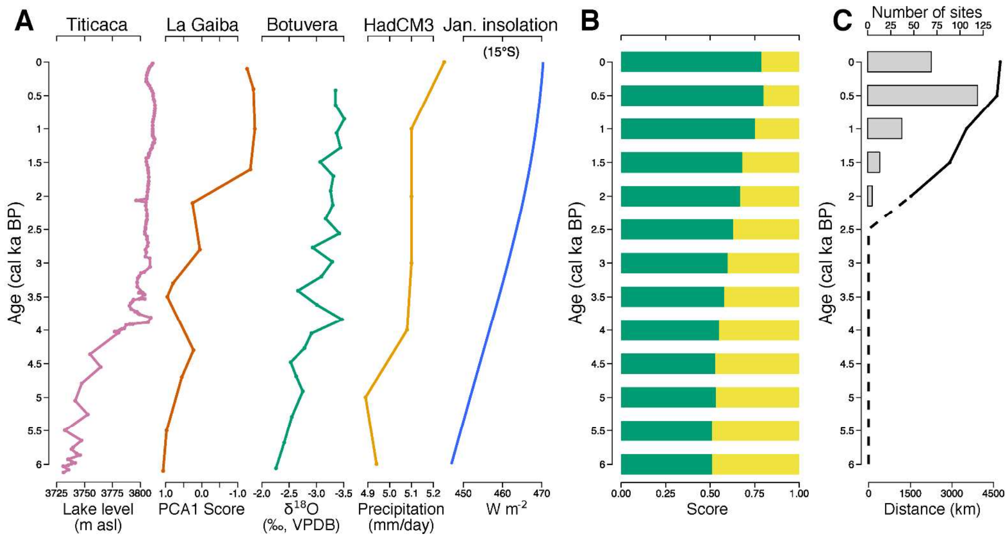

Figure 4. A. Selected palaeoclimate records representing proxies for precipitation changes over the last 6 k yr B.P., including lake-level changes as measured by δ13C at Lake Titicaca (Rowe et al., 2002); Pediastrum-inferred lake-level change at Laguna La Gaiba (Whitney and Mayle, 2012); δ18O of stalagmite BTV3A from Botuverá Cave (Wang et al., 2007) (Section S2, available online). Palaeoclimate data are shown in relation to HadCM3 simulated precipitation and calculated January insolation at 15°S (Berger and Loutre, 1991). B.Vegetation scores of forested (green) and non-forested (yellow) palaeoecological sites. The vegetation scores are a representation of the proportion of palaeoecological sites that reflect open vs. forested vegetation at a given time slice, with weighting applied according to the relative spatial coverage represented by each vegetation reconstruction (Section S3, available online). C. Number of archaeological sites per 500 yr time slices (Tables S1 and S2, available online). The curve shows maximum cumulative distance travelled at each time slice to colonise new areas (Section S1 and Figure S4, available online). The dashed line shows the probable distance travelled from the Tupian homeland to SE South America.
492x262mm (200 x 200 DPI)

Supplementary Material

Out of Amazonia: Late Holocene Climate Change and trans-continental Cultural Expansion

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Section S1. Archaeology

TupiGuarani archaeological sites. A list of the sites selected for this study (as mentioned in the main text) is Tables S1 and S2. Selection of dated sites related to the Guarani in southeast South America is facilitated by the fact that despite their immediate expansion over thousands of kilometres, they show remarkably homogeneous settlement patterns and material culture that clearly distinguish them from the local traditional cultures, over whose territories they rapidly expanded. In the definition given by Bonomo et al. (Bonomo et al., 2015), Guarani sites can be recognised by "1) ceramic dishes, shallow bowls and large jars (mainly restricted orifice, conical base and complex profiles with angle and inflection points), 2) corrugated surface treatments of the vessels, in addition to nail-incised, brushed or painted (red and/or black lines over white slip), 3) lip plugs named tembetás, 4) polished-stone axes, 5) secondary burials in urns and/or 6) bounded dark sediments named patches of terra preta sediment, associated with households and other architectural structures". In fact, ceramic vessels with complex profiles and whose surface is corrugated or polychrome painted are unmistakably Guarani in the context of southeast South America, as these traits are completely foreign to local traditions. The compilation of the Guarani dates benefited from previous syntheses (Bonomo et al., 2015; Corrêa, 2009, 2014; Noelli, 1999; Rogge, 2005). We filtered the data by excluding dates that were considered dubious by the excavators of the sites (Rogge, 2005). We also included dates that are not considered in recent syntheses (Bonomo et al., 2015), particularly for the states of Mato Grosso do Sul and São Paulo, where the distinction between Guarani and Tupinambá sites is controversial. The frontier between the Guarani and their northern relatives, the Tupinambá, is thought to lie somewhere between the Tietê and Paranapanema Rivers (Brochado, 1984; Scatamacchia, 1981, 1990). However, the similarity in Guarani and Tupinambá ceramic styles in this frontier zone makes the attribution of sites to one or the other subtradition difficult (Araujo, 2001). We consider the sites of the Paranapanema basin in the state of São Paulo as Guarani. We also see no reason to discard the earliest dates (from sites MS-PR-42 and MS-PR-57) in the Upper Paraná River, state of Mato Grosso do Sul, as they are clearly classified as "Tupiguarani" by the excavators (Kashimoto and Martins, 2008) and this is a consolidated area of Guarani occupation (Brochado, 1984; Noelli, 1999). We call attention to the fact that later strata from the same sites are undoubtedly Guarani (Kashimoto and Martins, 2008) and are included in the latest compilation of dates by (Bonomo et al., 2015).

The identification of the material correlates of proto-Tupían speakers in their homeland in southwest Amazon is a matter of debate. Unlike southeast South America, where polychrome pottery is almost a synonym of Tupi-Guarani speakers, there are various polychrome styles in the Amazon and they do not seem to be correlated to a single linguistic stock. The theory that the Amazon Polychrome Tradition (most famously represented by the Guarita and Marajoara ceramics) was produced by Tupi-Guarani speakers has been sustained by classical works on Amazonian archaeology (Brochado, 1984) and is still in vogue (Neves, 2010; Rebellato and Woods, 2012). This tradition, however, has been demonstrated to be of recent dispersal (Heckenberger et al., 1998; Moraes and Neves, 2012) and therefore is an unlikely correlate of the proto-Tupían groups. We have come to the conclusion that the early corrugated and polychrome ceramics of the state of Rondônia (Miller, 2009; Zimpel Neto, 2008) are so far the best candidates to represent the material culture of proto-Tupían speakers, based on their dates, ceramic characteristics, and geographic location close to the purported homeland. For the most recent debate on this subject, the reader is directed to Almeida (Almeida, 2013). Tables S1 and S2 include both thermoluminescence and radiocarbon dates. The later were calibrated with the southern hemisphere curve (Hogg et al., 2013) and the ranges represent the 2-sigma interval. Thermoluminescence dates do not require calibration and are reported in years BP counting from the date of the laboratory analysis. In addition to the ranges, we present the median as a point estimate of the calendric dates.

Travelled distance. This variable was calculated in order to measure how far the Guarani would have travelled to colonise new regions (Figure S2). The travelled distance is the largest distance between new sites and their nearest neighbours in the previous time slice. When expansion happened in more than one direction, we considered the largest distance. We measured both a linear distance and a "riverine/coastal" distance, considering the most likely route through major rivers or along the coast in order to reach the new destinations. We did not consider new sites emerging in close proximity between existing ones, but only those that expanded the Guarani territory. The curve in the graph of Fig. 2C in the main text represents the cumulative travelled distance through a riverine/coastal route, except in the case of the expansion between SW Amazonia and the Upper Paraná, for which a linear distance was calculated due to lack of archaeological information.

Section S2. Palaeoclimate

Palaeoclimate proxy data. Figure 2 in the main text includes palaeo precipitation curves taken from the following three empirical proxy record datasets spanning the last 6 kyr BP:

1. Laguna La Gaiba. Laguna La Gaiba is a large lake in the Pantanal wetlands that is hydrologically linked to the Paraguay River. Flooding of the river and therefore the basin is driven by the South American summer monsoon. Amazonian convective moisture is also delivered to the Pantanal region by via the South American Low Level Jet and the Chaco low, meaning that precipitation in this region is reflective of Amazonian moisture.
The curve presented in Figure 2 in the main manuscript is a score of relative lake level interpreted from fossil *Pediastrum* assemblages from the La Gaiba core (Whitney and Mayle, 2012). Lake level is taken as representative of precipitation change over the mid to late Holocene.

2. Lake Titicaca. Despite its location in the Altiplano, Lake Titicaca receives much of its moisture from the Amazon lowlands, making it a key rain gauge for the Amazon basin. The curve presented in Figure 2 in the main manuscript is a lake-level reconstruction derived from $\delta^{13}C$ isotope data (Abbott et al., 2003; Rowe et al., 2002).

3. Botuverá cave. Palaeoclimatic data from Botuverá cave was used as representative of the past climatic changes in the south east of South America. The record comes from a stalagmite obtained from Botuverá Cave (Cruz et al., 2005), providing a continuous record of palaeoclimate changes over subtropical Brazil. The curve from this record represented in Figure 2 in the main manuscript belongs to the oxygen stable isotope ($\delta^{18}O$%, VPDB) data. The variation of $\delta^{18}O$ has been interpreted by the authors as shifts in the source region and amount of rainfall in the area, and hence recording changes in atmospheric circulation and convective intensity over South America.

HadCM3 Model set up. HadCM3 is a GCM (General Circulation Model) consisting of coupled atmospheric, ocean and sea-ice model components (Gordon et al., 2000; Pope et al., 2000) and in this study we have included an additional coupled dynamic vegetation component. The resolution of the atmospheric model is 2.5° in latitude by 3.75° in longitude by 19 unequally spaced vertical levels. The spatial resolution over the ocean in HadCM3 is 1.25° by 1.25° by 20 unequally spaced layers in the ocean extending to a depth of 5200 m. The model contains a typical range of parameterizations in the atmosphere and ocean; further details are available elsewhere (Gordon et al., 2000; Pope et al., 2000) including details specific to the current model setup (Singarayer and Burrough, 2015). The model version used here incorporates the MOSES2.1 land surface scheme (Essery et al., 2003) and the TRIFFID vegetation model (Cox, 2001) run in 'equilibrium mode' (50 years of vegetation model following 5 years of climate model), which divide the land surface into nine surface types, including five plant functional types. HadCM3 is forced with prescribed changes in orbit (altering the seasonal and latitudinal distribution of solar insolation), greenhouse gases, sea level, and ice-sheet evolution. Orbital parameters are taken from published data (Berger and Loutre, 1991). Atmospheric concentrations of CO_2 were taken from Vostok (Loulergue et al., 2008; Petit et al., 1999) and CH_4, and N_2O were taken from EPICA (Spahni et al., 2005), with all data transferred to the EDC3 timescale (Parrenin et al., 2007). Ice-sheet, topography, bathymetry, and land-sea mask reconstructions use the ICE5G model (Peltier, 2004) for pre-industrial to LGM time slices, which includes a detailed evolution of the ice thickness, extent, and isostatic rebound for the last 21 kyr. In all simulations the initial conditions were the same, based on a prior spun-up pre-industrial simulation, and each was run to equilibrium for 500 years. The climatologies presented here are averages of the last 200 years.

One caveat of this 'snapshot' approach is that it assumes the climate is in equilibrium with the boundary conditions and is not affected by initial conditions (i.e. there are not multiple possible stable states). Previous publications using these and related model simulations suggest this is a reasonable first order approximation for the time-scale of climate variations we are considering in this study (Singarayer et al., 2011; Singarayer and Burrough, 2015; Singarayer and Valdes, 2010).

HadCM3 model results. HadCM3 annual mean Holocene rainfall (Figure S4) anomalies from 0 kyr BP (effectively a control pre-industrial simulation) show that mid-Holocene southern Amazonia experienced pervasive drier conditions to present. A principal cause of this drying is lower southern hemisphere summer insolation, resulting from of changes in orbital precession that shifted the continental rainfall belt north and generally resulted in lower convective activity. Regional palaeohydroclimate proxy records support the model rainfall trends. In contrast, to the north and northeast of the study region there are regions that experienced wetter conditions during the mid-Holocene than present. This orbitally-driven antiphasing of rainfall between northeast and southern Amazonia has been demonstrated through palaeorecords (Cruz et al., 2009). The consistency between key palaeorecords and HadCM3 simulations over the Holocene (Fig. S4) provide support for the robustness of the model palaeo-rainfall spatial and temporal trends.

Section S3. Palaeoecology

Palaeoecological sites. A multiproxy dataset of 73 palaeoecological sites, which are published in 54 separate papers, has been compiled (Tables S3- S6). Selected sites met the following criteria: a) they must fall within our research area of interest; b) they must have a vegetation reconstruction for at least two 500 yr time slices within the last 6,000 years BP.

This multiproxy compilation consists of various proxy types, summarised in Table S3. The majority of reconstructions (67%) are based solely or jointly on fossil pollen assemblages (POL), which are a direct reference to the vegetation that was growing in an area at the time the pollen was deposited. Reconstructions of fire activity from charcoal records (CHA) were also included as they provide information of both climatic changes and human presence/impact. The other reconstructions are based solely or jointly on isotopic carbon fractionation ($\delta^{13}C$, ISO), which distinguish between C_3 (trees) and C_4 (grasses) vegetation, which was deemed acceptable given that we were interested in examining broad-scale patterns of changing vegetation cover. Carbon isotope analysis was accepted where it was informed by modern vegetation-isotope analysis.

The quality of the dating and chronology varies among the palaeoecological sites. The number of control dates for a site ranged from 1 to 19 and it is variable as to whether any of the control dates fall within the last 6,000 years BP. Sub-sampling resolution also varied between sites. However, including sites with relatively few chronological control points was deemed acceptable as this study aims to get an overview of the vegetation trends over the last 6,000 years BP rather than identify exact timing of vegetation changes.

Time period and vegetation classification methodology. Time windows of 500 years were defined to visualise the changes of the vegetation from the fossil records across the whole region studied. For this aim each site was given a vegetation classification at 500-year time intervals (0.5k yrs BP) from 6,000 years BP (6k yrs BP) to the present (0k yrs BP).

To account for the vegetation changes, twelve broad vegetation classifications were defined for this analysis (shown in Table S4). Each classification followed the authors' interpretation of the vegetation reconstructions. For studies where a vegetation interpretation was not available (for example, when vegetation reconstruction was not a primary objective for a paper) our own interpretation was used. In this case, pollen and phytolith assemblages were classified with reference to modern pollen/phytolith analogue studies (Burn et al., 2010; Dickau et al., 2013; Gosling et al., 2005; Jones et al., 2011). Specific vegetation types were assigned for most cases, nevertheless when the vegetation was not easily distinguished from the pollen results a combination of these vegetation types was used (i.e. the 'savannah/grassland/shrubland' classification). For example, where vegetation was inferred from stable carbon isotope data, vegetation was assigned to the forest category as interpreted by the author, or generic forest where no forest type was specified. Broad categories such as generic forest, however, do not affect our analysis because the research question focuses on the transitions between open and forested landscapes.

In the cases where the interpretations suggest that vegetation at a given site was most likely a mixture of vegetation types, the use of a 'mosaic' classification (a combination of two classifications) was employed. The classifications for each site at each time step are shown in Table S4.

Vegetation score method. By using the proportion of forested vs non-forested sites to assess the relative amount of forested landscape within each time step would be inappropriate. This approach would not take account of i) the different spatial scale of the vegetation reconstruction represented at each site and ii) whether a site has a single or a mosaic classification. Therefore, we assigned a vegetation score to each site, which incorporates these two factors.

For our semi-quantitative treatment of the palaeoecological data, we assigned one of three different weightings to each site according to their size categories (see Table S5). Despite the relatively conservative weightings that we used, regional-scale trends in vegetation change are still apparent in our analysis.

The vegetation score, *V*, at a given time slice, *t,* can be expressed as:

$$V_t = \sum_{i=1}^{n_{sites}} c_i \times m_i \times s_i$$

where:

- c_i = classification weighting at site *i*, determined on whether the vegetation classification is within your chosen set of classifications, *C*:

$$c = \begin{cases} 1 & vegetation\ classification \in C \\ 0 & vegetation\ classification \notin C \end{cases}$$

- m_i = mosaic weighting at site *i*:

$$m = \begin{cases} 1 & 'full'\ classification \\ 0.5 & 'mosaic'\ classification \end{cases}$$

- s_i = size weighting at site *i*:

$$s = \begin{cases} 2 & large\ site \\ 1 & medium\ site \\ 0.5 & small\ site \end{cases}$$

A separate 'forested vegetation score' and 'non-forested vegetation score' was calculated for each time step. For the forested vegetation score, the classification set *C* is defined as:

$$C_f = \{HEF, SDF, GAL, ARF, CLF, FOR\}$$

For the non-forested vegetation score, the classification set *C* is defined as:

$$C_{nf} = \{SAV\}$$

(see Table S4 for descriptions of classifications).

The number of sites (n_{sites}) differs between each time step, so to be able to compare the vegetation scores between time steps we converted them into relative scores:

Relative 'forested' vegetation score, RV_f, at time slice *t* :

$$RV_{f,t} = \frac{V_{f,t}}{V_{f,t} + V_{nf,t}}$$

Relative 'non-forested' vegetation score, RV_{nf}, at time slice *t* :

$$RV_{nf,t} = \frac{V_{nf,t}}{V_{f,t} + V_{nf,t}}$$

Compilation of archaeological and palaeoecological data sets. The database of archaeological sites and palaeoecological records have been combined one figure, showing maps in time intervals of 0.5k yrs BP, starting at 6k yrs BP and until the present (0k yrs BP) (Movie S1). This set of 12 maps allows better visualisation of the expansion of Guarani populations (seen as stars appearing towards the SE of Brazil), synchronous with the expansion of forest (seen as increased number of green dots) across the whole region. A motion version displaying the 12 panels is also available in Movie S1 (available online).

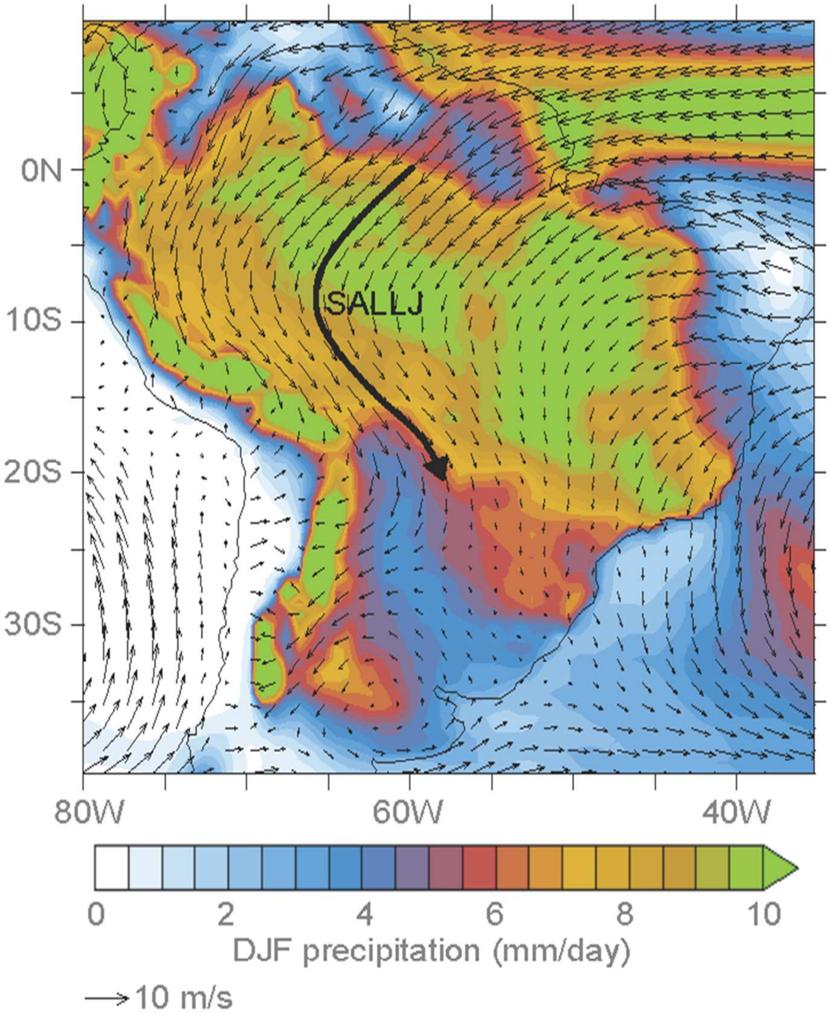

Fig. S1. December/January/February mean precipitation in mm/day (filled countours) and 850 mb winds from ERA Interim reanalysis (1979-2014 average) (Dee et al., 2011). The prevailing direction of the winds of the South American Low-Level Jet (SALLJ) is indicated by the long black arrow.

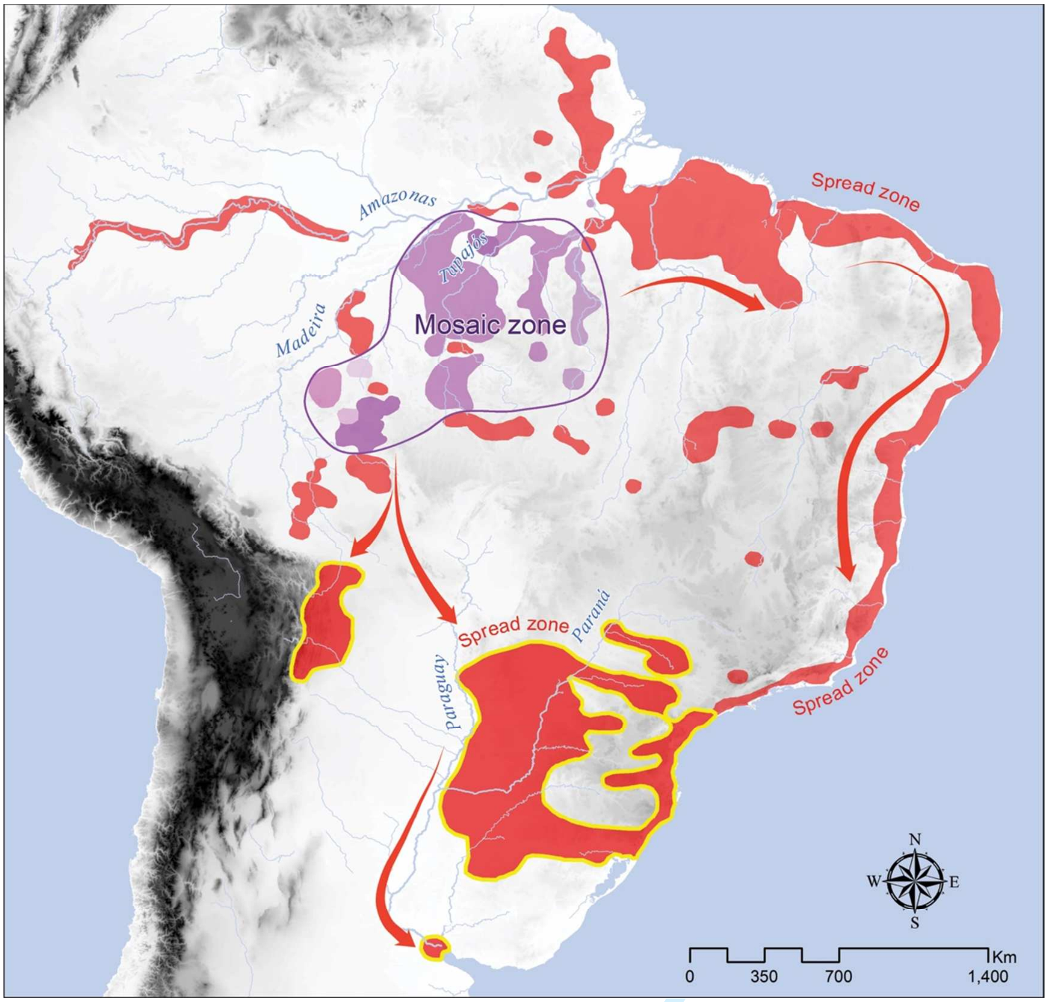

Figure S2. Historical distribution of the languages of the Tupi-Guarani family (red) and other families of the Tupían stock (shades of purple). Languages of the Group I (Guarani) are outlined in yellow. The map shows the Tupian mosaic zone characterise by high linguistic diversity resulting from a long period of uninterrupted divergence in the purported homeland of the stock originating in SW Amazonia and the Guarani spread zone, illustrating how this single language family rapidly dispersed over SE South America replacing previous languages.

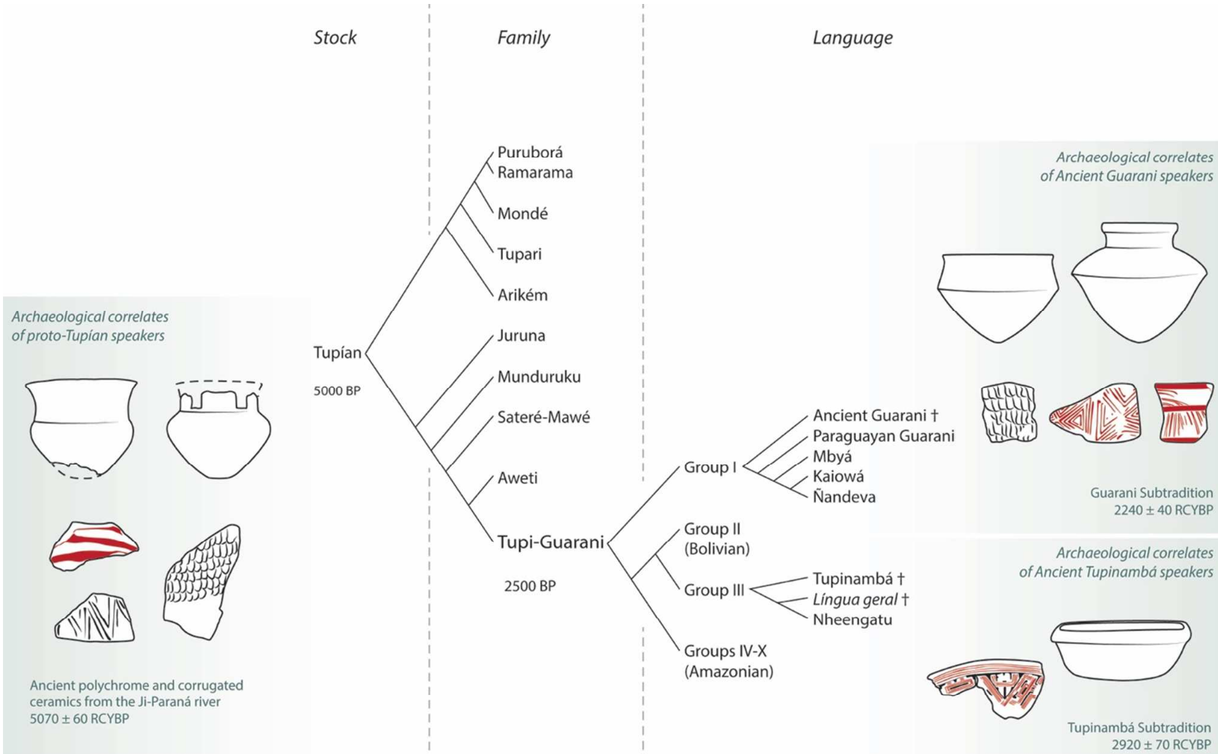

Figure S3. Phylogenetic tree showing the linguistic families of the Tupían stock and the main languages of the Tupi-Guarani family. Also shown are the most probable archaeological correlates, with their respective earliest dates, of the proto-Tupían, Guarani and Tupinambá (see Tables S1 and S2).

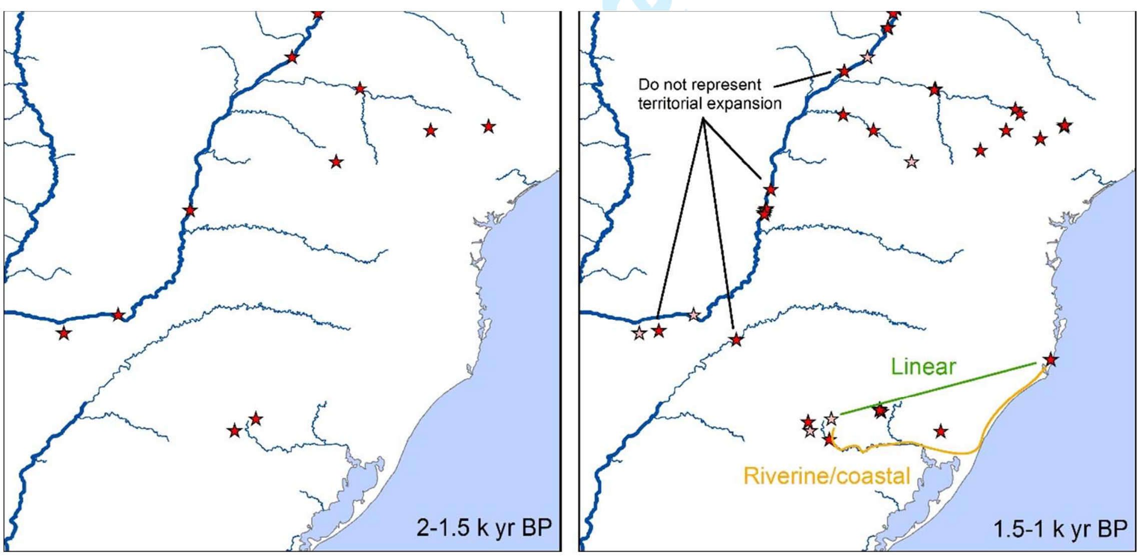

Figure S4. Diagram representing the method used to measure expanding Guarani populations or “Distance Travelled” (k yr BP: thousand years Before Present, stars: Guarani archaeological sites)

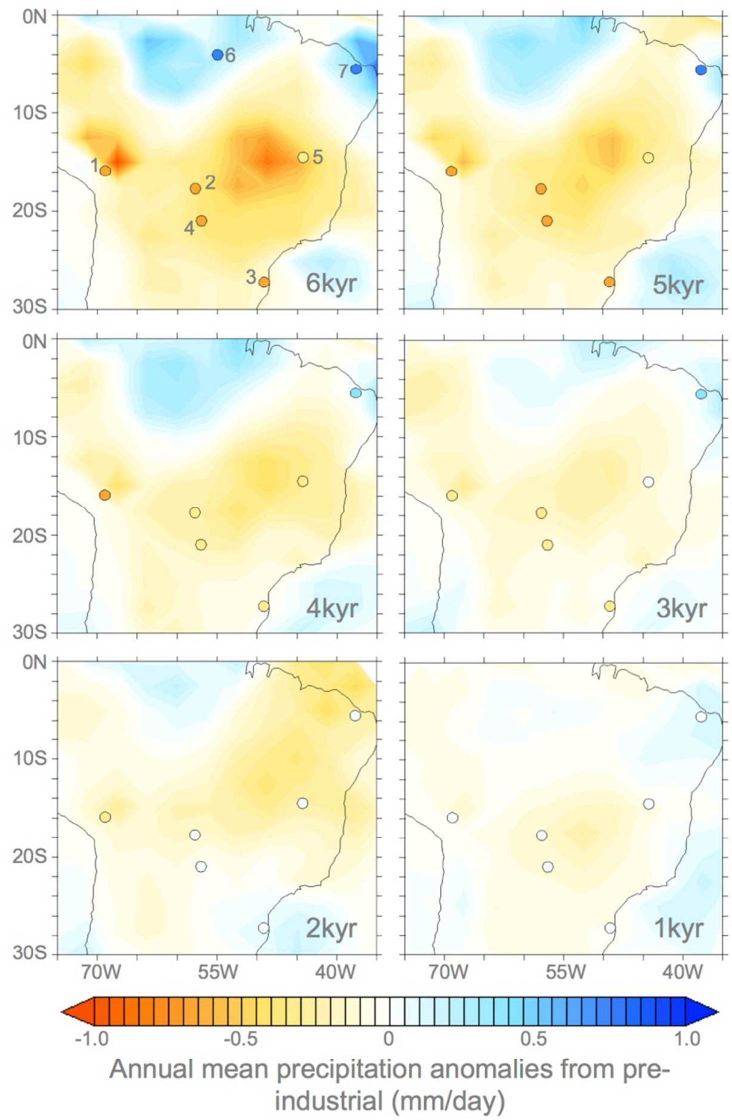

Figure S5. Modelled annual mean rainfall anomalies from pre-industrial (mm/day) as simulated by HadCM3 at 1000-yr intervals from 6 kyr BP (top left panel) to 1 kyr BP (bottom right). Overlying circles represent an inferred degree of wetness derived from key regional palaeoclimate records, labelled in the top left panel. The circle fill-colours indicate: blue - wetter than present, light blue - slightly wetter than present, white - no change, yellow - slightly drier than present, orange - drier than present. Palaeoclimate data sources used are as follows: (1) Lake Titicaca (2) Laguna La Gaiba (3) Botuverá Cave (4) Joao Arruda Cave (5) Lapa Grande (6) Paraiso Cave (7) Rio Grande do Norte.

Table S1

Dates of proto-Tupían sites in southwest Amazonia

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
RO-JI-15	5070 ± 60	5780	5915-5620	N/A	(Miller, 2009)	-61.930	-10.870	RO	C14
RO-JI-15	4230 ± 100	4705	4965-4435	N/A	(Miller, 2009)	-61.930	-10.870	RO	C14
RO-JI-17	3990 ± 70	4390	4785-4150	N/A	(Miller, 2009)	-61.870	-10.680	RO	C14
RO-MA-5	3910 ± 70	4285	4515-4085	Beta 230198	(Zimpel Neto, 2008)	-61.640	-11.070	RO	C14
RO-MA-5	3850 ± 80	4205	4425-3930	Beta 230198	(Zimpel Neto, 2008)	-61.640	-11.070	RO	C14
RO-JI-23A	3760 ± 70	4065	4295-3855	N/A	(Miller, 2009)	-61.920	-10.910	RO	C14

Table S2

Dates for Guarani sites

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-PR-42	2240 ± 40	2225	2335-2095	Gif 11227	(Kashimoto and Martins, 2008)	-51.993	-21.511	MS	C14
MS-PR-57		2100	2300-1900	Fatec 260	(Kashimoto, 2007)	-51.878	-21.209	MS	TL
Panema		2030	2230-1830	N/A	(Morais, 2000)	-48.480	-23.590	SP	TL
PR-FI-140	2010 ± 75	1925	2145-1730	SI 5028	(Chmyz, 1983)	-54.460	-25.200	PR	C14
MS-PR-22		1800	1840-1760	Fatec 185	(Kashimoto, 1997)	-52.399	-22.097	MS	TL
C-508	1880 ± 170	1780	2295-1370	LATYR LP 733	(Rodríguez, 2004)	-55.910	-27.310	Argentina	C14
SP-BA-7	1870 ± 100	1760	2000-1540	SI 418	(Brochado, 1973; Chmyz, 1967; Stuckenrath and Mielke, 1970)	-49.600	-23.583	SP	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
San Miguel II	1860 ± 50	1755	1875-1610	N/A	(Mujica, 1995a)	-57.004	-27.689	Argentina	C14
Joao Batista		1700	1930-1470	N/A	(Carle and Silva, 2007)	-51.506	-24.214	PR	TL
RS-MJ-88	1800 ± 100	1675	1905-1425	SI 2205	(Brochado, 1971, 1984)	-53.555	-29.659	RS	C14
Ragil		1660	1830-1490	Fatec	(Faccio, 1998)	-51.029	-22.738	SP	TL
MS-PR-57		1600	1800-1400	Fatec 259	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
Valdeci Scapini		1550	-	N/A	(Bona, 2006)	-53.130	-29.420	RS	N/A
Angoaguasu	1680 ± 90	1540	1740-1320	UA 10240	(Pärssinen, 2005)	-63.850	-20.410	Bolivia	C14
Jango Luis		1540	1690-1390	N/A	(Pallestrini, 1975)	-48.430	-23.500	SP	TL
Placitu Mayu	1675 ± 80	1530	1715-1355	UA 10238	(Pärssinen, 2005)	-64.430	-19.620	Bolivia	C14
Joao Batista		1510	1710-1310	N/A	(Carle and Silva, 2007)	-51.506	-24.214	PR	TL
Almeida		1500	1650-1350	N/A	(Morais, 2000; Pallestrini, 1975)	-49.350	-23.283	SP	TL
MS-PR-85		1493	1593-1393	N/A	(Kashimoto, 2007)	-51.660	-20.930	MS	TL
PR-FI-118	1625 ± 60	1470	1610-1320	SI 5021	(Chmyz, 1983)	-54.350	-24.780	PR	C14
Rio Uruguai	1570 ± 100	1435	1700-1270	N/A	(Piazza, 1969)	-53.730	-27.170	SC	C14
PR-FI-99	1565 ± 70	1420	1560-1300	SI 5019	(Chmyz, 1983)	-54.480	-25.250	PR	C14
RS-T-101		1411	1411-1411	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-114		1410	1525-1295	Lacifid-USP	(Kreutz, 2008)	-52.119	-29.277	RS	TL
MS-PR-57		1400	1520-1280	Fatec 262	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
PR WB 2		1343	1433-1253	N/A	(Chmyz, 2008)	-50.120	-23.980	PR	TL
PR-FL-21	1490 ± 45	1340	1420-1280	SI 1011	(Brochado, 1973, 1984; Stuckenrath and Mielke, 1973)	-52.280	-23.580	PR	C14
RS-MJ-60	1475 ± 80	1340	1520-1180	SI 2203	(Brochado, 1971, 1984)	-53.600	-29.480	RS	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-PR-57		1300	1420-1180	Fatec 266	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
MS-PR-57		1270	1400-1140	Fatec 263	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
PR-FI-142	1395 ± 60	1265	1370-1090	SI 5033	(Chmyz, 1983)	-54.440	-25.170	PR	C14
MS-PR-45	1380 ± 40	1260	1315-1180	GIF 12026	(Kashimoto, 2007; Kashimoto and Martins, 2008)	-51.980	-21.500	MS	C14
Jango Luis		1260	1260-1260	N/A	(Pallestrini, 1975)	-48.430	-23.500	SP	TL
MS-PR-86		1250	1400-1100	Fatec 171	(Kashimoto and Martins, 2008)	-51.620	-20.930	MS	TL
MS-PR-64		1248	1348-1148	Fatec 194	(Kashimoto, 1997)	-51.824	-21.119	MS	TL
MS-PR-86	1380 ± 70	1240	1360-1070	Gif 11224	(Kashimoto and Martins, 2008)	-51.620	-20.930	MS	C14
Jose Vieira	1380 ± 150	1235	1540-935	GSY 81	(Chmyz, 1968)	-52.890	-23.270	PR	C14
RS-S-282	1380 ± 110	1235	1470-975	SI 414	(Miller, 1967; Stuckenrath and Mielke, 1970)	-50.917	-29.667	RS	C14
MS-PR-86		1225	1375-1075	Fatec 173	(Kashimoto and Martins, 2008)	-51.620	-20.930	MS	TL
RS-T-110		1222	1222-1222	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
RS-T-110		1204	1204-1204	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
MS-IV-8		1200	1350-1050	Fatec 148	(Kashimoto and Martins, 2008; Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PR-57		1200	1320-1080	Fatec 267	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
MS-PR-86		1200	1350-1050	Fatec 148	(Kashimoto and Martins, 2008)	-51.620	-20.930	MS	TL
Fonseca		1190	1310-1070	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-IV-8		1170	1310-1030	Fatec 164	(Martins et al., 1999: 199)	-52.869	-22.384	MS	TL
RS-T-101		1147	1147-1147	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
MS-PR-71		1130	1250-1010	Fatec 103	(Kashimoto, 2007)	-51.810	-21.110	MS	TL
Santa Tecla I	1260 ± 140	1125	1375-805	AC 1337	(Rodríguez, 1997)	-56.615	-27.637	Argentina	C14
RS-MJ-101	1255 ± 100	1125	1300-935	SI 2201	(Brochado, 1971; Schmitz and Brochado, 1972)	-53.170	-29.836	RS	C14
RS-T-114		1122	1220-1024	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
RS-T-101		1121	1121-1121	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
PR-FI-97	1235 ± 60	1110	1270-965	SI 5016	(Chmyz, 1983)	-54.480	-25.280	PR	C14
Fonseca		1110	1220-1000	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL
MS-PR-42		1110	1220-1000	Fatec 398	(Kashimoto and Martins, 2008)	-51.993	-21.511	MS	TL
Fonseca		1100	1200-1000	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL
MS-PR-57		1100	1200-1000	Fatec 250	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
Sao Roque		1100	1200-1000	N/A	(Morais, 2000)	-48.410	-23.480	SP	TL
RS-T-101		1099	1099-1099	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-VZ-4	1220 ± 120	1095	1310-810	SI 708	(Miller, 1969; Stuckenrath and Mielke, 1973)	-55.050	-27.817	RS	C14
Ragil II		1093	1193-993	Fatec	(Faccio, 1998)	-51.033	-22.757	SP	TL
RS-T-114		1090	1186-994	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
Fonseca		1076	1076-1076	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL
Camargo II		1070	1170-970	N/A	(Morais, 2000)	-49.410	-23.160	SP	TL
SP-BA-7	1195 ± 80	1065	1270-925	SI 1009	(Brochado, 1973; Chmyz, 1967;	-49.600	-23.583	SP	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					Stuckenrath and Mielke, 1970)				
IMA-23		1050	1160-940	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-48.697	-28.217	SC	TL
RS-MJ-60	1180 ± 70	1045	1265-925	SI 2204	(Brochado, 1971; Schmitz and Brochado, 1972)	-53.600	-29.480	RS	C14
IMA-23		1040	1150-930	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-48.697	-28.217	SC	TL
RS-T-101		1040	1040-1040	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-MJ-60	1150 ± 70	1020	1185-815	SI 2202	(Goldmeier and Schmitz, 1983)	-53.600	-29.480	RS	C14
Alves		1020	1120-920	N/A	(Morais, 2000; Pallestrini, 1975)	-49.316	-23.250	SP	TL
Fonseca		1010	1110-910	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL
SP-AS-14	1130 ± 150	1005	1290-730	SI 422	(Chmyz, 1967; Stuckenrath and Mielke, 1973)	-51.050	-22.767	SP	C14
IMA-23		1000	1100-900	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-48.697	-28.217	SC	TL
MS-PR-57		1000	1110-890	Fatec 253	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
MS-VD-2		1000	-	Fatec 392	(Kashimoto, 2007)	-51.890	-21.180	MS	TL
IBM-14		985	1085-885	LVD 2174	(Zuse, 2009: 2)	-54.220	-29.550	RS	TL
RS-T-101		981	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
Jango Luis		980	1080-880	N/A	(Pallestrini, 1975)	-48.430	-23.500	SP	TL
MS-PD-7		980	1080-880	Fatec 402	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.621	-21.707	MS	TL
Alvim		978	1078-878	N/A	(Faccio, 1992)	-51.755	-22.603	SP	TL
Fonseca		970	1070-870	N/A	(Morais, 2000; Pallestrini, 1975)	-48.910	-23.750	SP	TL
Alves		960	1060-860	N/A	(Morais, 2000; Pallestrini, 1975)	-49.316	-23.250	SP	TL
Alves		955	1055-855	N/A	(Morais, 2000; Pallestrini, 1975)	-49.316	-23.250	SP	TL
MS-IV-8		950	1065-835	Fatec 163	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-T-101		950	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
Alvim		942	-	N/A	(Faccio, 1992)	-51.755	-22.603	SP	TL
MS-PR-96		940	1040-840	Fatec 174	(Kashimoto, 2007)	-51.610	-20.910	MS	TL
RS-LN-35	1070 ± 110	935	1185-725	SI 413	(Brochado et al., 1969; Miller, 1967; Stuckenrath and Mielke, 1970)	-50.083	-29.767	RS	C14
SC-U-69	1070 ± 100	930	1180-735	SI 549	(Brochado, 1973; Piazza, 1969; Stuckenrath and Mielke, 1972)	-53.433	-27.133	SC	C14
MS-IV-8		930	1040-820	Fatec 166	(Martins et al., 1999)	-52.869	-22.384	MS	TL
PR-ST-1	1065 ± 95	925	1175-735	SI 695	(Brochado, 1973; Chmyz, 1969; Stuckenrath and Mielke, 1973)	-52.600	-23.320	PR	C14
SC-PRV-1	1040	925	935-905	N/A	(Bigarella, 1949; Duarte, 1972;	-48.410	-27.480	SC	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					Rohr, 1969)				
Peroba		917	1017-817	N/A	(Morais, 2000)	-50.040	-22.880	SP	TL
MS-PR-90		909	989-829	N/A	(Kashimoto, 1997)	-51.610	-20.910	MS	TL
RS-T-114		908	995-821	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
Alvim		906	996-816	N/A	(Faccio, 1992)	-51.755	-22.603	SP	TL
MS-PR-57		900	990-810	Fatec 251	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
RS-T-110		893	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
Camargo	1030 ± 100	885	1090-680	N/A	(Morais, 1999, 2000)	-49.417	-23.167	SP	C14
Isla del Vizcaino	1020 ± 130	885	1180-670	URU 117	(Coirolo, 1990)	-58.425	-33.426	Uruguay	C14
MS-PR-57		880	960-800	Fatec 255	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
Nunes		880	970-790	N/A	(Morais, 2000; Pallestrini, 1988)	-49.380	-23.180	SP	TL
Pajeu		875	965-785	N/A	(Morais, 2000)	-50.510	-22.910	SP	TL
Colina		870	960-780	N/A	(Morais, 2000)	-49.380	-23.180	SP	TL
MS-PR-64	1015 ± 75	865	1055-730	Gif 10039	(Kashimoto, 1997, 2007)	-51.824	-21.119	MS	C14
RS-T-101		864	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-101		856	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
SP-AS-14	980 ± 100	845	1055-670	SI 709	(Noelli, 1999; Stuckenrath and Mielke, 1973)	-51.050	-22.767	SP	C14
MS-MI-01	970 ± 60	840	955-725	Beta 238765	(Bespalez, 2009)	-56.282	-20.560	MS	C14
RS-T-101		838	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
MS-IV-8		835	925-745	Fatec 162	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-MJ-1		830	910-750	Lab Fisica USP	(Kashimoto and Martins, 2008)	-55.390	-21.774	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
RS-T-114		830	902-758	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
Varzea dos Bugres		830	960-700	N/A	(Santi, 2009)	-53.480	-29.520	RS	TL
RS-T-101		829	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-110		822	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
Figueira		820	900-740	N/A	(Morais, 2000)	-50.510	-22.910	SP	TL
RS-T-110		820	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
Almeida	930 ± 100	810	980-650	N/A	(Morais, 2000; Pallestrini, 1975)	-49.350	-23.283	SP	C14
IMA-23		810	895-725	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-48.697	-28.217	SC	TL
RS-T-110		808	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
MS-IV-8		800	900-700	Fatec 139	(Martins et al., 1999)	-52.869	-22.384	MS	TL
Panambi 3	920 ± 70	795	925-680	LP 176	(Poujade, 1994; Sempé and Caggiano, 1995)	-54.901	-27.692	Argentina	C14
MS-IV-8		795	895-695	Fatec 156	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		795	890-700	Fatec 150	(Martins et al., 1999)	-52.869	-22.384	MS	TL
Olho D'agua I	920 ± 60	790	920-680	Beta 280652	(Milheira, 2010)	-49.190	-28.780	SC	C14
RS-MJ-53a	905 ± 95	785	960-650	SI 1196	(Brochado, 1969, 1973)	-53.332	-29.417	RS	C14
RS-T-101		782	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-114		779	-	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
PR-RP-11		777	827-727	N/A	(Chmyz, 2008)	-50.330	-24.000	PR	TL
SC-U-71	900 ± 50	765	905-675	Beta 118377	(Noelli, 1999)	-51.750	-27.498	SC	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
Isla del Vizcaino	870 ± 100	760	935-565	URU 118	(Castillo, 2004; Coirolo, 1990)	-58.425	-33.426	Uruguay	C14
RS-LN-35	870 ± 100	760	935-565	SI 412	(Brochado, 1973; Miller, 1967; Stuckenrath and Mielke, 1970)	-50.083	-29.767	RS	C14
MS-IV-8		760	820-700	Fatec 247	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
RS-RG-2	890 ± 40	755	905-675	SI 1190	(Brochado, 1984; Carle, 2002; Naue, 1973; Schmitz, 1976)	-52.222	-31.847	RS	C14
SP-BA-7	850 ± 150	755	1050-525	SI 417	(Brochado, 1973; Chmyz, 1967; Stuckenrath and Mielke, 1970)	-49.600	-23.583	SP	C14
Neves		755	835-675	Fatec	(Faccio, 1998)	-50.967	-22.348	SP	TL
MS-IV-8		750	830-670	Fatec 89	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		750	830-670	Fatec 248	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
MS-PD-7		750	800-700	Fatec 400	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.621	-21.707	MS	TL
PR-SA-44		750	825-675	N/A	(Chmyz, 2008)	-50.880	-24.090	PR	TL
Cerro do Tope		740	775-705	N/A	(Santi, 2009)	-53.490	-29.520	RS	TL
Varzea dos Bugres		740	910-570	LVD 2362	(Santi, 2009)	-53.480	-29.520	RS	TL
RS-T-110		736	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
PR-WB-15		732	780-684	N/A	(Chmyz, 2008)	-49.870	-23.950	PR	TL
RS-T-110		731	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
MS-IV-8		730	820-640	Fatec 147	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-T-107		727	-	N/A	(Cano et al.,	-52.020	-29.400	RS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					2012)				
Lagoa dos Esteves		720	790-650	N/A	(Lino, 2007)	-49.296	-28.841	SC	TL
RS-T-114		720	804-636	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
RS-T-114		717	915-519	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
RS-VZ-43	830 ± 60	715	900-570	N/A	(Miller, 2009)	-53.740	-27.340	RS	C14
IMA-23		715	790-640	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-48.697	-28.217	SC	TL
RS-T-101		714	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-107		712	-	N/A	(Cano et al., 2012)	-52.020	-29.400	RS	TL
MS-PR-42	840 ± 40	710	775-665	Gif 11226	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-51.993	-21.511	MS	C14
Piapara		710	780-640	N/A	(Morais, 2000)	-49.380	-23.180	SP	TL
Valenzuela	810 ± 60	700	795-565	B 197128	(Rodríguez, 2009)	-56.730	-27.520	Argentina	C14
MD-1		700	775-625	Fatec 88	(Kashimoto and Martins, 2008)	-51.780	-20.960	MS	TL
MS-IV-8		700	850-550	Fatec 169	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
MS-PR-57		700	770-630	Fatec 265	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
PR-WB-15		698	744-652	N/A	(Chmyz, 2008)	-49.870	-23.950	PR	TL
RS-SM-7	800 ± 40	695	750-570	SI 1003	(Brochado, 1969; Stuckenrath and Mielke, 1973)	-54.250	-29.550	RS	C14
Caieira	795 ± 95	695	905-545	N/A	(Hurt, 1974)	-48.770	-28.430	SC	C14
Isla del Vizcaino	790 ± 105	690	905-545	URU 118	(Castillo, 2004; Coirolo, 1990)	-58.425	-33.426	Uruguay	C14
RS-T-110		690	-	N/A	(Cano et al.,	-52.150	-29.220	RS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					2012)				
MS-IV-8		680	760-600	Fatec 149	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-T-110		678	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
RS-MJ-98	775 ± 65	675	770-555	SI 2198	(Brochado, 1971, 1984)	-53.249	-29.761	RS	C14
SC-U-53	770 ± 100	675	905-530	SI 439	(Brochado et al., 1969; Mielke and Long, 1969; Piazza, 1969)	-53.417	-27.200	SC	C14
RS-T-110		670	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
RS-T-101		667	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
PR-FO-4	760 ± 40	665	730-565	SI 5039	(Chmyz, 1983)	-54.250	-24.070	PR	C14
PR-JA-2	760 ± 50	660	735-560	SI 140	(Chmyz, 1967; Long, 1965)	-49.990	-22.900	PR	C14
RS-C-14	745 ± 115	660	905-505	SI 1198	(Ribeiro, 1968, 1974)	-51.373	-29.629	RS	C14
RS-T-101		653	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
PR-FI-140	745 ± 75	650	755-545	SI 5027	(Chmyz, 1983)	-54.460	-25.200	PR	C14
RS-T-114		650	719-581	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
PR-RP-12		649	694-604	N/A	(Chmyz, 2008)	-50.320	-24.000	PR	TL
MS-PR-57		630	690-570	Fatec 256	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
PR-WB-7		626	666-586	N/A	(Chmyz, 2008)	-49.960	-23.960	PR	TL
Santa Tecla I	684 ± 170	625	925-320	AC 1338	(Rodríguez, 1997)	-56.615	-27.637	Argentina	C14
MS-IV-8		625	685-565	Fatec 146	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		625	675-575	Fatec 246	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
MS-PR-35		625	665-585	Fatec 189	(Kashimoto and Martins, 2008)	-52.058	-21.631	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
Figueira		624	-	N/A	(Morais, 2000)	-50.510	-22.910	SP	TL
PR-SA-5		623	668-578	N/A	(Chmyz, 2008)	-50.640	-24.010	PR	TL
RS-T-114		622	-	N/A	(Cano et al., 2012)	-52.119	-29.277	RS	TL
PR-FI-112	700 ± 55	615	685-545	SI 5036	(Chmyz, 1983)	-54.350	-24.750	PR	C14
RS-T-101		613	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-101		612	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-MJ-87	695 ± 55	610	680-540	SI 2200	(Brochado, 1971, 1984)	-53.644	-29.678	RS	C14
Arroyo Fredes	690 ± 70	610	720-525	UGA 10789	(Loponte et al., 2011)	-58.568	-34.209	Argentina	C14
SC-MA-01	650	610	635-555	N/A	(Mauricio, 2008)	-48.760	-28.450	SC	C14
ARA-10		610	670-550	N/A	(Farias and Kneip, 2010; Lavina, 2000; Lino, 2007; Milheira, 2010)	-49.320	-28.870	SC	TL
Lagoa Mae Luzia		610	680-540	N/A	(Lino, 2007)	-49.323	-28.866	SC	TL
MS-IV-8		610	664-556	Fatec 152	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		610	685-535	Fatec 91	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PD-7		610	670-550	Fatec 399	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.621	-21.707	MS	TL
Quiteroi 5		610	670-550	Fatec 118	(Martins et al., 1999)	-52.661	-22.159	MS	TL
RS-T-114		609	-	N/A	(Cano et al., 2012)	-52.119	-29.277	RS	TL
Pajeu		607	-	N/A	(Morais, 2000)	-50.510	-22.910	SP	TL
RS-VZ-52	675 ± 50	605	670-545	N/A	(Miller, 2009)	-54.070	-27.300	RS	C14
MS-IV-8		605	675-535	Fatec 158	(Martins et al.,	-52.869	-22.384	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					1999)				
Cerro de las Pajas Blancas I	650 ± 70	600	675-515	LP 1925	(Bonomo et al., 2011)	-60.740	-32.120	Argentina	C14
MS-IV-8		600	680-520	Fatec 142	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-9		600	657-543	Fatec 997	(Kashimoto and Martins, 2008)	-53.715	-23.244	MS	TL
MS-PR-96		600	660-540	Fatec 105	(Kashimoto, 2007)	-51.610	-20.910	MS	TL
Cerro de las Pajas Blancas I	640 ± 70	595	670-510	LP 2046	(Bonomo et al., 2011)	-60.740	-32.120	Argentina	C14
PR-FI-100	625 ± 55	595	660-515	SI 5020	(Chmyz, 1983)	-54.480	-25.270	PR	C14
MS-IV-8		595	665-525	Fatec 145	(Martins et al., 1999)	-52.869	-22.384	MS	TL
Marolo		594	654-534	N/A	(Morais, 2000)	-50.400	-22.770	SP	TL
RS-T-110		593	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
RS-T-107		592	-	N/A	(Cano et al., 2012)	-52.020	-29.400	RS	TL
RS-T-114		592	659-525	N/A	(Kreutz, 2008)	-52.119	-29.277	RS	TL
Arroyo Negro		590	-	UCTL 1673	(Farías Gluchy, 2005)	-58.189	-32.497	Uruguay	TL
MS-IV-8		590	660-520	Fatec 161	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-T-107		588	-	N/A	(Cano et al., 2012)	-52.020	-29.400	RS	TL
SC-U-55	620 ± 80	585	675-495	SI 550	(Brochado, 1973; Piazza, 1969; Stuckenrath and Mielke, 1972)	-53.083	-27.117	SC	C14
Martins		580	640-520	N/A	(Morais, 1995, 2000)	-50.010	-22.630	SP	TL
MS-PR-39		580	620-540	Fatec 190	(Kashimoto, 1997; Kashimoto and Martins, 2008; Martins et al., 1999)	-52.106	-21.541	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
Piracanjuba		580	650-510	N/A	(Afonso et al., 2005; Morais, 2001)	-49.370	-23.140	SP	TL
PR-ST-1	610 ± 120	575	740-325	SI 696	(Brochado, 1973; Stuckenrath and Mielke, 1973)	-52.600	-23.320	PR	C14
San Antonio	610 ± 70	575	665-500	Beta 105247	(Rodríguez, 2009)	-56.738	-27.514	Argentina	C14
RS-T-110		574	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
MS-MJ-1	610 ± 50	570	650-510	GIF 8330	(Martins et al., 1999)	-55.390	-21.774	MS	C14
Piracanjuba	610 ± 50	570	650-510	N/A	(Afonso et al., 2005; Morais, 2001)	-49.370	-23.140	SP	C14
RS-C-71	610 ± 50	570	650-510	Beta	(Dias and Silva, 2013; Gaulier, 2001)	-51.163	-30.265	RS	C14
MS-IV-9		570	610-530	Fatec 996	(Kashimoto and Martins, 2008)	-53.715	-23.244	MS	TL
MS-PR-42		570	630-510	Fatec 397	(Kashimoto and Martins, 2008)	-51.993	-21.511	MS	TL
MS-PR-85		570	610-530	Fatec 195	(Kashimoto, 2007)	-51.660	-20.930	MS	TL
PR-SA-9		570	616-524	N/A	(Chmyz, 2008)	-50.680	-24.010	PR	TL
RS-T-110		569	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
PR-FI-103	600 ± 60	565	655-500	SI 5029	(Chmyz, 1983)	-54.450	-25.200	PR	C14
MS-PR-55		565	627-533	Fatec 193	(Kashimoto, 1997)	-51.971	-21.240	MS	TL
RS-LC-82		563	608-518	LVD 665	(Rogge, 2005)	-50.605	-30.431	RS	TL
RS-SM-7	605 ± 40	560	645-510	SI 1002	(Brochado, 1969, 1973; Stuckenrath and Mielke, 1973)	-54.250	-29.550	RS	C14
PR-FL-15	590 ± 70	560	660-490	SI 699	(Brochado, 1973; Stuckenrath and	-52.320	-23.540	PR	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					Mielke, 1973)				
SC-VP-38	590 ± 100	560	720-325	SI 826	(Brochado, 1973; Miller, 1969, 1971; Stuckenrath and Mielke, 1973)	-52.508	-27.271	SC	C14
Almeida		560	620-500	N/A	(Morais, 2000; Pallestrini, 1975)	-49.350	-23.283	SP	TL
RS-T-114		560		Beta 249391	(Fiegenbaum, 2009)	-52.119	-29.277	RS	C14
PR-FI-127	590 ± 55	555	650-500	SI 5024	(Chmyz, 1983)	-54.410	-24.930	PR	C14
RS-T-101		554	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-110		554	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
MS-IV-8		550	600-500	Fatec 90	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		550	620-480	Fatec 138	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PR-86		550	620-480	Fatec 168	(Kashimoto, 2007)	-52.860	-22.380	MS	TL
RS-T-107		547	-	N/A	(Cano et al., 2012)	-52.020	-29.400	RS	TL
SC-AW-1	590	545	555-535	Beta 217835	(Farias and Kneip, 2010: 2010)	-48.660	-28.220	SC	C14
Llamarada 1	580 ± 50	545	640-495	Beta 41941	(Mujica, 1995a: 199, 1995b)	-58.082	-28.319	Argentina	C14
RS-RG-2	580 ± 50	545	640-495	Beta 64560	(Carle, 2002)	-52.222	-31.847	RS	C14
MS-IV-8		545	610-480	Fatec 154	(Martins et al., 1999)	-52.869	-22.384	MS	TL
Olho D'agua I	570 ± 40	540	630-500	Beta 280652	(Milheira, 2010; Milheira and DeBlasis, 2011)	-49.197	-28.780	SC	C14
Santa Tecla I	570 ± 50	540	640-495	B 197129	(Rodríguez, 2009)	-56.615	-27.637	Argentina	C14
Campina		540	590-490	N/A	(Morais, 1999,	-48.477	-23.580	SP	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					2000)				
ON-1		540	600-480	Fatec 117	(Kashimoto and Martins, 2008)	-52.925	-22.398	MS	TL
Rio Amambai 1		540	580-500	Fatec 127	(Kashimoto and Martins, 2008)	-55.164	-23.964	MS	TL
Varzea dos Bugres		540	610-470	LVD 2179	(Santi, 2009)	-53.480	-29.520	RS	TL
SC-PR-1	565	535	550-520	Beta 217837	(Farias and Kneip, 2010)	-48.660	-28.220	SC	
Cabeçuda 2	560	535	545-520	Beta 242800	(Farias and Kneip, 2010; Oliveira, 2010)	-48.810	-28.440	SC	C14
PR-FL-23	560 ± 60	535	650-470	SI 700	(Brochado, 1973, 1984; Stuckenrath and Mielke, 1973)	-52.280	-23.600	PR	C14
Praia da Tapera	550 ± 70	535	655-335	SI 244	(Chmyz, 1976; Long and Mielke, 1967; Rohr, 1969)	-48.501	-27.594	SC	C14
PR-SA-1		531	571-491	N/A	(Chmyz, 2008)	-50.570	-24.020	PR	TL
RS-T-107		531	-	N/A	(Cano et al., 2012)	-52.020	-29.400	RS	TL
RS-T-110		531	-	N/A	(Cano et al., 2012)	-52.150	-29.220	RS	TL
Sibelco	550 ± 60	530	650-455	Beta 262752	(Milheira, 2010; Milheira and DeBlasis, 2011)	-48.999	-28.610	SC	C14
Piracanjuba		530	590-470	N/A	(Afonso et al., 2005; Morais, 2001)	-49.370	-23.140	SP	TL
PR-QN-2	540 ± 60	525	640-335	SI 697	(Brochado, 1973; Chmyz, 1969; Stuckenrath and Mielke, 1973)	-52.770	-23.270	PR	
RS-SR-342	540 ± 60	525	640-335	Beta 118375	(Hilbert, 1999)	-51.533	-29.981	RS	C14
MS-IV-8		525	555-495	Fatec 165	(Martins et al., 1999)	-52.869	-22.384	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
RS-T-101		525	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-LN-16	540 ± 100	520	665-320	SI 411	(Brochado, 1973; Miller, 1967; Stuckenrath and Mielke, 1970)	-50.217	-29.933	RS	C14
Maximiliano de Almeida	530 ± 70	520	650-325	N/A	(Noelli, 1999)	-51.810	-27.530	RS	C14
PR-NL-7	530 ± 55	520	635-340	SI 6400	(Chmyz and Chmyz, 1986)	-52.856	-22.641	PR	C14
PS-03	530 ± 40	520	560-485	Beta 237665	(Milheira, 2008)	-52.195	-31.711	RS	C14
SC-U-368	530 ± 70	520	650-325	Beta 118375	(Noelli, 1999)	-51.768	-27.533	SC	C14
PR-CT-54	528 ± 70	520	650-325	Beta 22645	(Chmyz, 1983)	-49.380	-25.470	PR	C14
Ensenada del Bellaco	526 ± 45	520	625-465	AA 103895	(Bonomo et al., 2015)	-58.435	-33.091	Argentina	C14
Bersi		520	580-460	N/A	(Morais, 2000)	-49.340	-23.400	SP	TL
MS-IV-8		520	580-460	Fatec 159	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PR-57		520	570-470	Fatec 261	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
MS-PR-86		520	580-460	Fatec 159	(Kashimoto and Martins, 2008)	-52.860	-22.380	MS	TL
RS-MJ-47e	530 ± 100	515	655-320	SI 816	(Brochado, 1971, 1973; Stuckenrath and Mielke, 1973)	-53.380	-29.850	RS	C14
Llamarada 1	520 ± 50	515	625-340	Beta 41942	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14
Morro Bonito I	520 ± 50	515	625-340	Beta 262753	(Milheira, 2010; Milheira and DeBlasis, 2011)	-49.884	-28.605	SC	C14
SC-AR-1	520	515	530-505	Beta 202015	(Farias and Kneip, 2010)	-48.680	-28.120	SC	C14
SC-AW-1	519	515	525-500	Beta 217834	(Farias and Kneip, 2010)	-48.660	-28.220	SC	C14
Morro Bonito III	510 ± 40	515	555-465	Beta 262755	(Milheira, 2010; Milheira and	-48.992	-28.601	RS	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					DeBlasis, 2011)				
PS-03	510 ± 40	515	555-465	Beta 282128	(Alves, 2012)	-52.195	-31.711	RS	C14
Llamarada 1	510 ± 50	510	625-335	Beta 41942	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14
MS-PR-57	510 ± 50	510	625-335	Beta 218207	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	C14
RS-RG-2	510 ± 60	510	630-325	Beta 64284	(Carle, 2002)	-52.222	-31.847	RS	C14
PR-UV-16	500 ± 45	510	555-335	SI 1015	(Chmyz, 1969; Stuckenrath and Mielke, 1973)	-51.040	-26.230	PR	C14
PSGPA-04		510	580-440	Fatec 1968	(Milheira, 2008)	-52.405	-31.490	RS	TL
Rio Uruguai	510 ± 70	505	635-325	N/A	(Piazza, 1969)	-53.730	-27.170	SC	C14
SC-U-55	510 ± 70	505	635-325	SI 547	(Noelli, 1999; Piazza, 1969; Stuckenrath and Mielke, 1972)	-53.083	-27.117	SC	C14
Llamarada 1	500 ± 60	505	625-325	Beta 41945	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14
MS-IV-8		505	565-445	Fatec 153	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-T-101		503	-	N/A	(Cano et al., 2012)	-52.150	-29.240	RS	TL
RS-T-114		503	-	N/A	(Cano et al., 2012)	-52.119	-29.277	RS	TL
Barra do Santo Cristo 1	500 ± 70	500	630-320	LP 1874	(Angrizani, 2012)	-54.720	-27.568	RS	C14
MS-IV-8		500	550-450	Fatec 143	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-IV-8		500	560-440	Fatec 264	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
Piracanjuba		500	560-440	N/A	(Afonso et al., 2005; Morais, 2001)	-49.370	-23.140	SP	TL
PR-FO-3	490 ± 60	495	560-325	SI 5040	(Chmyz, 1983)	-54.254	-24.077	PR	C14
Llamarada 1	480 ± 50	495	550-325	Beta 41944	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
SC-VX-5	490 ± 70	490	625-320	SI 548	(Brochado, 1973; Miller, 1971; Stuckenrath and Mielke, 1973)	-53.017	-27.100	SC	C14
Arroio Corrente V	470 ± 40	490	545-330	Beta 280654	(Milheira, 2010; Milheira and DeBlasis, 2011)	-49.036	-28.674	SC	C14
MS-IV-8		490	550-430	Fatec 144	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-LN-16	520 ± 200	480	790-...	SI 410	(Brochado, 1973; Miller, 1967; Stuckenrath and Mielke, 1970)	-50.217	-29.933	RS	C14
MS-IV-1	475 ± 60	480	555-320	SI 1017	(Chmyz, 1969, 1974; Stuckenrath and Mielke, 1973)	-53.330	-22.720	MS	C14
MS-IV-8		480	540-420	Fatec 141	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PR-98		480	510-450	Fatec 196	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-54.042	-23.597	MS	TL
Piracanjuba		480	530-430	N/A	(Afonso et al., 2005; Morais, 2000)	-49.370	-23.140	SP	TL
RS-CM-11	445 ± 40	470	525-325	SI 6402	(Ribeiro et al., 1986)	-52.892	-30.845	RS	C14
Piracanjuba		470	525-415	N/A	(Afonso et al., 2005; Morais, 2000)	-49.370	-23.140	SP	TL
Laranjal I	440 ± 40	465	520-325	Beta 262751	(Milheira, 2010)	-48.938	-28.608	SC	C14
PR-FL-05	470 ± 100	460	640-285	SI 694	(Brochado, 1973; Chmyz, 1969; Stuckenrath and Mielke, 1973)	-52.591	-23.316	PR	C14
Arroyo Malo	442 ± 45	460	525-320	AA 103897	(Bonomo et al., 2015)	-58.698	-34.306	Argentina	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-IV-8		460	515-405	Fatec 137	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PR-40		460	510-410	Fatec 99	(Kashimoto and Martins, 2008)	-52.073	-21.503	MS	TL
Morro Bonito II	430 ± 40	455	515-320	Beta 262754	(Milheira, 2010; Milheira and DeBlasis, 2011)	-48.984	-28.597	SC	C14
Medina I	430 ± 50	445	515-320	LP 734	(Rodríguez, 2009)	-57.149	-27.552	Argentina	C14
MS-PR-22	370 ± 20	445	500-320	Gif 11073	(Kashimoto, 1997)	-52.399	-22.097	MS	C14
MS-IV-8		445	480-410	Fatec 140	(Martins et al., 1999)	-52.869	-22.384	MS	TL
Cem. A. Paicarabi y Fredes	421 ± 45	440	510-320	AA 103896	(Bonomo et al., 2015)	-58.592	-34.229	Argentina	C14
Arroyo la Glorieta	416 ± 41	435	505-320	AA 93216	(Bonomo et al., 2011)	-58.744	-34.346	Argentina	C14
MS-IV-8		435	485-385	Fatec 160	(Martins et al., 1999)	-52.869	-22.384	MS	TL
MS-PD-4		432	464-400	Fatec 187	(Kashimoto, 1997)	-52.785	-22.186	MS	TL
Gonzalez	420 ± 50	430	510-320	B 105251	(Rodríguez, 2009)	-56.729	-27.506	Argentina	C14
RS-SR-342	420 ± 60	425	515-310	Beta 118376	(Hilbert, 1999)	-51.533	-29.981	RS	C14
SC-U-368	420 ± 60	425	515-310	Beta 118376	(Noelli, 1999)	-51.768	-27.533	SC	C14
MS-IV-8		425	450-400	Fatec 183	(Martins et al., 1999)	-52.869	-22.384	MS	TL
El Arbolito	405 ± 35	420	500-320	GrN 5146	(Cigliano, 1968)	-58.260	-34.127	Argentina	C14
MS-IV-8		420	470-370	Fatec 157	(Martins et al., 1999)	-52.869	-22.384	MS	TL
PR-FI-104	415 ± 75	415	530-295	SI 5032	(Chmyz, 1983)	-54.459	-25.197	PR	C14
519	410 ± 50	415	505-315	B 197133	(Rodríguez, 1997, 2009)	-56.169	-27.356	Argentina	C14
Tres Bocas 2	410 ± 60	415	510-305	LP 1761	(Angrizani, 2012)	-54.656	-27.529	RS	C14
MS-PD-6		415	455-375	Fatec 406	(Kashimoto and Martins, 2008)	-52.500	-21.703	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
Arroyo Fredes	402 ± 40	410	500-320	AA 77309	(Loponte et al., 2011)	-58.568	-34.209	Argentina	C14
Llamarada 1	400 ± 50	410	505-315	Beta 41939	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14
MS-PR-45		410	450-370	Fatec 107	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-51.980	-21.500	MS	TL
PR-FI-142	395 ± 60	405	505-305	SI 5033	(Chmyz, 1983)	-54.440	-25.170	PR	C14
Itajuba 1	390 ± 60	400	505-300	LP 1751	(Angrizani, 2012)	-54.668	-27.544	RS	C14
Santa Tecla I	390 ± 60	400	505-300	Beta 197130	(Rodríguez, 2009)	-56.615	-27.637	Argentina	C14
516	380 ± 50	400	495-305	B 197132	(Rodríguez, 2009)	-56.269	-27.415	Argentina	C14
PS-02	380 ± 50	400	495-305	Beta 234205	(Milheira, 2008)	-52.174	-31.698	RS	C14
Arroyo Fredes	370 ± 50	395	495-305	LP 1428	(Loponte et al., 2011)	-58.568	-34.209	Argentina	C14
Llamarada 1	370 ± 60	395	505-295	Beta 41943	(Mujica, 1995a, 1995b)	-58.082	-28.319	Argentina	C14
Medina I	360 ± 60	390	500-285	Beta 105253	(Rodríguez, 2009)	-57.149	-27.552	Argentina	C14
MS-PR-35		390	430-350	Fatec 396	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.058	-21.631	MS	TL
PR-FI-118	340 ± 60	380	500-150	SI 5023	(Chmyz, 1983)	-54.359	-24.780	PR	C14
Medina I	330 ± 50	380	495-155	LP 750	(Rodríguez, 1997, 2009)	-57.149	-27.552	Argentina	C14
MS-PR-18		380	420-340	Fatec 106	(Kashimoto and Martins, 2008)	-52.493	-22.113	MS	TL
MS-PR-26		380	420-340	Fatec 122	(Kashimoto and Martins, 2008)	-52.377	-22.018	MS	TL
MS-PR-48		380	420-340	Fatec 108	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.019	-21.417	MS	TL

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-PR-57		380	420-340	Fatec 264	(Kashimoto and Martins, 2008)	-51.878	-21.209	MS	TL
MS-IV-8		375	420-335	Fatec 151	(Martins et al., 1999)	-52.869	-22.384	MS	TL
RS-MJ-50a	345 ± 105	360	530-...	SI 818	(Brochado, 1971, 1973; Stuckenrath and Mielke, 1973)	-53.550	-29.689	RS	C14
Santa Tecla I	310 ± 50	360	470-150	Beta 197131	(Rodríguez, 2009)	-56.615	-27.637	Argentina	C14
Piracanjuba		360	400-320	N/A	(Afonso et al., 2005; Morais, 2000)	-49.370	-23.140	SP	TL
MS-IV-8		350	390-310	Fatec 136	(Kashimoto and Martins, 2008)	-52.869	-22.384	MS	TL
MS-PR-28		350	385-315	Fatec 116	(Kashimoto and Martins, 2008)	-52.421	-21.940	MS	TL
MS-PR-8		350	390-310	Fatec 96	(Kashimoto and Martins, 2008)	-52.628	-22.207	MS	TL
Poco Grande		340	375-305	N/A	(Farias and Kneip, 2010; Lino, 2007)	-48.844	-26.445	RS	TL
Medina I	300 ± 50	325	470-150	Beta 105248	(Rodríguez, 2009)	-57.149	-27.552	Argentina	
Valenzuela	300 ± 50	325	470-150	B 105250	(Rodríguez, 2009)	-56.730	-27.520	Argentina	C14
MS-PR-8		320	355-285	Fatec 94	(Kashimoto and Martins, 2008; Martins et al., 1999)	-52.628	-22.207	MS	TL
PR-FL-05	300 ± 115	300	505-...	SI 693	(Brochado, 1973; Chmyz, 1969; Stuckenrath and Mielke, 1973)	-52.591	-23.316	PR	C14
MS-PR-8		300	350-250	Fatec 95	(Kashimoto and Martins, 2008)	-52.628	-22.207	MS	TL
RS-LC-80	280 ± 50	295	455-70	Beta 202366	(Rogge, 2005; Schmitz and	-50.605	-30.431	RS	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					Sandrin, 2009)				
Bianco		295	325-265	N/A	(Araujo, 2001)	-48.946	-24.024	SP	TL
MS-PR-26		290	320-260	Fatec 123	(Kashimoto and Martins, 2008)	-52.377	-22.018	MS	TL
Panema		290	330-250	N/A	(Morais, 2000)	-48.480	-23.590	SP	TL
MS-PR-46		280	295-265	Fatec 192	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.018	-21.427	MS	TL
MS-PD-7		275	295-255	Fatec 188	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.621	-21.707	MS	TL
RS-MJ-71	265 ± 90	255	470-...	SI 2199	(Brochado, 1971, 1984)	-53.536	-29.532	RS	C14
MS-PD-6		250	275-225	Fatec 405	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.500	-21.703	MS	TL
MS-IV-1	260 ± 70	245	455-...	SI 1016	(Chmyz, 1969, 1974; Stuckenrath and Mielke, 1973)	-53.330	-22.720	MS	C14
MS-PR-41		245	250-230	Fatec 191	(Kashimoto, 1997; Kashimoto and Martins, 2008)	-52.067	-21.492	MS	TL
MS-PR-13		239	249-229	Fatec 184	(Kashimoto, 1997)	-52.703	-22.136	MS	TL
PR-FI-97	255 ± 80	230	455-...	SI 5017	(Chmyz, 1983)	-54.480	-25.280	PR	C14
SC-U-54	250 ± 90	225	455-...	SI 546	(Brochado, 1973; Piazza, 1969; Stuckenrath and Mielke, 1972)	-53.033	-27.083	SC	C14
MS-PD-6	240 ± 30	200	310-140	Gif 10038	(Kashimoto, 1997; Kashimoto and Martins,	-52.500	-21.703	MS	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
					2008)				
Santa Tecla I	240 ± 50	200	440-...	Beta 105252	(Rodríguez, 2009)	-56.615	-27.637	Argentina	C14
PR-FI-22	230 ± 80	200	445-...	SI 5015	(Chmyz, 1983)	-54.603	-25.445	PR	C14
RS-VZ-12	215 ± 105	195	450-...	SI 702	(Brochado, 1973; Stuckenrath and Mielke, 1973)	-55.100	-27.800	RS	C14
RS-VZ-41	225 ± 55	190	320-...	SI 701	(Brochado, 1973; Miller, 1969; Stuckenrath and Mielke, 1973)	-53.733	-27.167	RS	C14
RS-MJ-90	220 ± 85	190	445-...	SI 2202	(Brochado, 1971, 1984)	-52.681	-29.729	RS	C14
PR-FI-118	205 ± 80	180	440-...	SI 5022	(Chmyz, 1983)	-54.359	-24.780	PR	C14
RS-C-63	190 ± 85	170	435-...	SI 1197	(Ribeiro, 1968, 1974; Rogge, 2005)	-51.565	-29.372	RS	C14
PR-FI-98	190 ± 75	165	320-...	SI 5018	(Chmyz, 1983)	-54.484	-25.285	PR	C14
RS-MJ-50b	110 ± 150	165	445-...	SI 817	(Brochado, 1969, 1984; Stuckenrath and Mielke, 1973)	-53.550	-29.689	RS	C14
PR-FL-13	135 ± 120	155	440-...	SI 698	(Brochado, 1973; Chmyz, 1969; Stuckenrath and Mielke, 1973)	-52.321	-23.549	PR	C14
MS-IV-1	180 ± 60	150	285-...	SI 1018	(Chmyz, 1969, 1974; Stuckenrath and Mielke, 1973)	-53.330	-22.720	MS	C14
RS-SM-5	180 ± 60	150	285-...	SI 3523	(Ribeiro, 1991)	-52.681	-29.729	RS	C14
RS-MJ-42a	130 ± 105	140	425-...	SI 815	(Brochado, 1969, 1984; Stuckenrath and Mielke, 1973)	-53.383	-29.824	RS	C14
PR-FI-104	85 ± 75	110	280-...	SI 5030	(Chmyz, 1983)	-54.459	-25.197	PR	C14

Site	RCYBP	m Cal yr BP	Cal yr BP	Lab#	Reference	X	Y	State	Obs
MS-IV-2	110 ± 60	105	280-...	SI 1019	(Chmyz, 1969, 1974; Stuckenrath and Mielke, 1973)	-53.320	-22.710	MS	C14
PR-FO-6	85 ± 60	100	280-...	SI 5041	(Chmyz, 1983)	-54.265	-24.076	PR	C14

Table S3

Proxy types used in this study

Proxy code	Proxy type
POL	Pollen
CHA	Charcoal
CHM	Chemical/Physico-chemical
ISO	Isotopic analysis
TLU	Thermoluminescence
SED	Sedimentological analysis
DIA	Diatoms
PHY	Phytoliths

Table S4

Vegetation classifications defined in this study based on the interpretation given in the respective publications

Code	Vegetation classification
HEF	Humid evergreen tropical forest
SDF	Seasonally dry tropical forest
GAL	Gallery forest
SAV	Savannah/Grassland/Shrubland
ARF	Araucaria forest
WET	Wetland/Marsh
LAG	Lagoon (coastal)
PSW	Palm swamp
MAN	Mangroves
CLF	Cloud/montane forest
FOR	Generic forest category (when specific forest category cannot be determined)
RES	Restinga - coastal forest

Table S5

Size categories defined for the catchment areas considered in the palaeoecological sites included in this study

Category	Definition	Weighting
Large	Lakes larger than $5km^2$	2
Medium	Lakes between $800m^2$ and $5km^2$	1
Small	Soil pits, bogs and lakes less than $800m^2$	0.5

Table S6

Full list of palaeoecological sites used in this study. *: *see Table S3*

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Anhembi	-22.75	-47.9667	SE Brazil	CHA / ISO	0	7,800	(Gouveia et al., 2002; Pessenda, 2004)
Ariquemes	-10.1667	-62.8167	W Brazil	ISO	0	3,270	(Pessenda et al., 1998)
Bairro Lajeado	-24.3051	-48.3651	SE Brazil	ISO	0	> 19,000	(Saia et al., 2008)
Base do Carmo	-24.3069	-48.4144	SE Brazil	ISO	0	> 13,000	(Saia et al., 2008)
Botucatu	-23	-48	SE Brazil	CHA / ISO	0	8,000	(Gouveia et al., 2002; Pessenda, 2004)
Bulha D'Água	-24.3375	-48.5025	SE Brazil	ISO			(Saia et al., 2008)
Cambará do Sul	-29.0525	-50.1011	S Brazil	POL / CHA	0	43,000	(Behling et al., 2004; Behling and Pillar, 2007)
Centro de Pesquisas e Conservação da Natureza	-29.4747	-50.1631	SE Brazil	ISO	0	8,000	(Dümig et al., 2008)
Fazenda do Pinto	-29.4	-50.5667	S Brazil	POL	0	3,970	(Behling et al., 2001)
Figueirinha Lake Peat Bog	-28.6607	-48.9897	SE Brazil	POL / DIA / CHM	0	> 25,000	(Carvalho do Amaral et al., 2012)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Humaitá HU01	-7.9239	-63.0831	W Brazil	POL / CHM / ISO	0	39,000	(Cohen et al., 2014)
Humaitá soil profiles	-8.1725	-63.8463	W Brazil	ISO	0	10,000	(Pessenda et al., 2001)
Iporanga and Bairro Camargo Baixo and Lagoa Grande	-24.5553	-48.6575	SE Brazil	POL / ISO			(Pessenda et al., 2010; Saia et al., 2008)
Itajuru Farm	-29.5867	-55.2172	S Brazil	POL / CHA	50	22,000	(Behling et al., 2005)
Jacareí peat	-23.2833	-45.9667	SE Brazil	POL	1,950	9,700	(Garcia et al., 2004)
Jaguariúna	-22.6667	-47.0167	SE Brazil	CHA / ISO	0	9,200	(Gouveia et al., 2002; Pessenda, 2004)
Lago Consuelo	-13.95	-68.9833	SE Peru	POL	0	48,000	(Bush et al., 2004)
Laguna Bella Vista	-13.6167	-61.55	NE Bolivia	POL / CHA	0	50,000	(Burbridge et al., 2004; Mayle et al., 2000)
Laguna Chaplin	-14.4667	-61.0667	NE Bolivia	POL / CHA	0	43,000	(Burbridge et al., 2004; Mayle et al., 2000)
Laguna El Cerrito	-13.2472	-65.3858	N Bolivia	POL / CHA	0	1,000	(Whitney et al., 2014)
Laguna Frontera	-13.2203	-65.3533	N Bolivia	POL / CHA	0	1,700	(Whitney et al., 2014)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Laguna Granja	-13.2622	-63.7103	NE Bolivia	POL / CHA	0	6,100	(Carson et al., 2014, 2015)
Laguna Khomer Kocha Upper	-17.2752	-65.7324	C Bolivia	POL / CHA / CHM	0	18,000	(Williams et al., 2011a)
Laguna La Gaiba	-17.7615	-57.7158	E Bolivia	POL / DIA	0	42,000	(Whitney et al., 2011)
Laguna Orícore	-13.3456	-63.5255	NE Bolivia	POL / CHA	0	5,700	(Carson et al., 2014)
Laguna San José	-14.9495	-64.495	N Bolivia	POL / CHA / PHY	0	3,000	(Whitney et al., 2013)
Laguna Sucuara	-16.8267	-62.0433	E Bolivia	ISO / CHM / TLU / SED	0	9,500	(Zech et al., 2009)
Laguna Yaguarú	-15.6	-63.2167	E Bolivia	POL / CHA / ISO	0	> 5,600	(Taylor et al., 2010)
Lake Chalalán	-14.4278	-67.9208	NE Bolivia	POL / CHA	0	16,700	(Urrego et al., 2013)
Lake Challacaba	-17.596	-65.5683	C Bolivia	POL / CHA / CHM	0	4,070	(Williams et al., 2011b)
Lake Gentry	-12.1773	-69.0977	E Peru	POL / CHA	0	6,200	(Bush et al., 2007a, 2007b)
Lake Parker	-12.1411	-69.0216	E Peru	POL / CHA	0	7,400	(Bush et al., 2007a, 2007b)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Lake Santa Rosa	-14.4769	-67.8747	NE Bolivia	POL / CHA	0	15,700	(Urrego et al., 2013)
Lake Siberia	-17.8333	-64.71667	C Bolivia	ISO	0	30,000	(Sifeddine et al., 2004)
Lake Vargas	-12.3733	-68.9014	E Peru	POL / CHA	0	7,900	(Bush et al., 2007a, 2007b)
Lake Werth	-11.7466	-69.2365	E Peru	POL / CHA	0	3,200	(Bush et al., 2007a, 2007b)
Londrina	-23.3	-51.1667	SE Brazil	CHA / ISO	0	7,600	(Pessenda, 2004)
Los Ajos	-33.7	-53.95	SE Urug uay	POL / PHY	0	14,800	(Iriarte, 2006)
Machado soil core	-21.6783	-45.9242	SE Brazil	PHY / ISO	0	12,500	(Calegari et al., 2013)
Misiones	-27.39	-55.525	NE Argentin a	ISO / CHM / TLU / SED	0	41,000	(Morrás et al., 2009; Zech et al., 2009)
Morro da Igreja	-28.1833	-49.8667	S Brazil	POL	0	10,200	(Behling, 1995, 1998)
Morro de Itapeva	-22.7833	-45.5333	SE Brazil	POL / CHA	0	35,000	(Behling, 1997a, 1998)
Morro Santana	-30.0756	-51.1014	S Brazil	POL / CHA	0	1,200	(Behling et al., 2007b)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Parque Provincial Cruce Caballero	-26.5154	-53.9958	NE Argentina	POL / CHA	0	1,900	(Gessert et al., 2011)
Pedra do Sino	-22.4583	-43.0281	SE Brazil	POL / CHA	0	12,300	(Behling and Safford, 2009)
Pessenda 2009 soil profiles + Colonia crater	-23.9873	-46.7403	SE Brazil	ISO	0	27,000	(Ledru et al., 2005, 2009; Ruiz Pessenda et al., 2009)
Pimenta Bueno (cerradão)	-11.8167	-61.1667	W Brazil	ISO	0	> 7,000	(Pessenda et al., 1998)
Piracicaba	-22.7167	-47.6333	SE Brazil	CHA / ISO	0	7,600	(Pessenda, 2004)
Poco Grande	-26.416	-48.8667	S Brazil	POL	3,000	5,000	(Behling, 1995, 1998)
Pontes e Lacerda	-15.2667	-59.2167	W Brazil	CHA / ISO	0	7,500	(Gouveia et al., 2002)
Porto Rico - Paraná River	-22.7167	-53.1667	S Brazil	POL / TLU / SED	0	40,000	(Stevaux, 2000)
Porto Velho PV02	-8.7786	-63.9467	W Brazil	POL / CHM / ISO	0	3,700	(Cohen et al., 2014)
Riachinho Valley	-28.6419	-48.9976	SE Brazil	POL / DIA / CHM	0	5,200	(Carvalho do Amaral et al., 2012)
Rincão das Cabritas	-29.4764	-50.5728	S Brazil	POL / CHA	0	16,700	(Jeske-Pieruschka and Behling, 2012)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Saibadela	-24.2403	-48.0811	SE Brazil	ISO	0	16,000	(Saia et al., 2008)
Sajama	-18.1	-68.8833	E Bolivia	POL / CHM / ISO	0	25,000	(Reese et al., 2013; Thompson, 1998)
Sangão River valley core	-28.6426	-49.0669	SE Brazil	POL / DIA / CHM	0	2,800	(Carvalho do Amaral et al., 2012)
Santo Antônio da Patrulha	-29.7458	-50.5489	SE Brazil	POL / CHA	0	5,500	(Macedo et al., 2010)
Serra Campos Gerais	-24.6667	-50.2167	S Brazil	POL / CHA	0	12,480	(Behling, 1997b, 1998: 199)
Serra da Boa Vista	-27.7	-49.15	S Brazil	POL	0	14,000	(Behling, 1995, 1998)
Serra da Bocaina 2	-22.7139	-44.5667	SE Brazil	POL	1,280	10,380	(Behling et al., 2007a)
Serra da Igreja	-25.6	-48.85	SE Brazil	ISO	0	3,000	(Scheer et al., 2013)
Serra do Araçatuba	-25.9167	-48.9833	S Brazil	POL / CHA	0	15,000	(Behling, 2006)
Serra do Rio Rostro	-28.3833	-49.55	S Brazil	POL	0	11,210	(Behling, 1995, 1998)

Site name	Latitude (°)	Longitude (°)	Country	Proxy code*	Minimum age (yr BP)	Maximum age (yr BP)	Reference(s)
Serra do Tabuleiro peat core	-27.8968	-48.8681	S Brazil	POL / CHA	0	39,700	(Jeske-Pieruschka et al., 2013)
Serra Velha	-29.6061	-51.6486	S Brazil	POL	0	9,800	(Leal and Lorscheitter, 2007)
Sítio Grande mangrove	-25.0833	-47.9333	S Brazil	POL / DIA / ISO	0	> 40,000	(Pessenda et al., 2012)
TU Peat Bog	-23.9833	-46.7458	SE Brazil	POL	0	28,500	(Ruiz Pessenda et al., 2009)
Vilhena	-12.7	-60.1167	W Brazil	ISO	0	> 5,900	(Pessenda et al., 1998)
Volta Velha	-26.0667	-48.633	S Brazil	POL	3,000	37,640	(Behling and Negrelle, 2001)

Movie S1

Archaeological, palaeoeclimatic and palaeoecological data at 0.5k (500 years) time slices.

Online references

Abbott MB, Wolfe BB, Wolfe AP, Seltzer GO, Aravena R, Mark BG, et al. (2003) Holocene paleohydrology and glacial history of the central Andes using multiproxy lake sediment studies. *Palaeogeography, Palaeoclimatology, Palaeoecology* 194(1–3): 123–138: doi:10.1016/S0031-0182(03)00274-8.

Afonso MC, Mendonça CA, Morais JL and Piedade SC (2005) Investigações geofísicas no sítio Piracanjuba (Piraju, SP). paper presented at the XIII Congresso da Sociedade de Arqueologia Brasileira. Sociedade de Arqueologia Brasileira.

Almeida FO (2013) A Tradição Polícroma no Alto Rio Madeira. São Paulo, Universidade de São Paulo.

Alves AG (2012) Análise espacial em um sítio Guarani no litoral sudoeste da Laguna dos Patos, Sítio PS-03 Totó - RS. São Paulo, Universidade de São Paulo.

Angrizani RC (2012) Variabilidad, Movilidad y Paisaje: una propuesta interpretativa para los vestigios de los asentamientos precoloniales en el noroeste del Rio Grande do Sul (Brasil). La Plata, Universidad Nacional de La Plata.

Araujo AG de M (2001) Teoria e método em arqueologia regional: um estudo de caso no alto Paranapanema, Estado de São Paulo. PhD Dissertation, Sao Paulo, Universidade de Sao Paulo.

Behling H (1995) Investigations into the late Pleistocene and Holocene history of vegetation and climate in Santa Catarina (S Brazil). *Vegetation History and Archaeobotany* 4(3). Available at: http://link.springer.com/10.1007/BF00203932: doi:10.1007/BF00203932.

Behling H (1997a) Late Quaternary vegetation, climate and fire history from the tropical mountain region of Morro de Itapeva, SE Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology* 129(3-4): 407–422: doi:10.1016/S0031-0182(97)88177-1.

Behling H (1997b) Late Quaternary vegetation, climate and fire history of the Araucaria forest and campos region from Serra Campos Gerais, ParanáState (South Brazil). *Review of Palaeobotany and Palynology* 97(1-2): 109–121: doi:10.1016/S0034-6667(96)00065-6.

Behling H (1998) Late Quaternary vegetational and climatic changes in Brazil. *Review of Palaeobotany and Palynology* 99(2): 143–156: doi:10.1016/S0034-6667(97)00044-4.

Behling H (2006) Late Quaternary vegetation, fire and climate dynamics of Serra do Araçatuba in the Atlantic coastal mountains of Paraná State, southern Brazil. *Vegetation History and Archaeobotany* 16(2-3): 77–85: doi:10.1007/s00334-006-0078-2.

Behling H, Bauermann SG and Pereira Neves PC (2001) Holocene environmental changes in the São Francisco de Paula region, southern Brazil. *Journal of South American Earth Sciences* 14(6): 631–639: doi:10.1016/S0895-9811(01)00040-2.

Behling H, Dupont L, DeForest Safford H and Wefer G (2007a) Late Quaternary vegetation and climate dynamics in the Serra da Bocaina, southeastern Brazil. *Quaternary International* 161(1): 22–31: doi:10.1016/j.quaint.2006.10.021.

Behling H and Negrelle RRB (2001) Tropical Rain Forest and Climate Dynamics of the Atlantic Lowland, Southern Brazil, during the Late Quaternary. *Quaternary Research* 56(3): 383–389: doi:10.1006/qres.2001.2264.

Behling H and Pillar VD (2007) Late Quaternary vegetation, biodiversity and fire dynamics on the southern Brazilian highland and their implication for conservation and management of modern Araucaria forest and grassland ecosystems. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362(1478): 243–251: doi:10.1098/rstb.2006.1984.

Behling H, Pillar VD and Bauermann SG (2005) Late Quaternary grassland (Campos), gallery forest, fire and climate dynamics, studied by pollen, charcoal and multivariate analysis of the São Francisco de Assis core in western Rio Grande do Sul (southern Brazil). *Review of Palaeobotany and Palynology* 133(3-4): 235–248: doi:10.1016/j.revpalbo.2004.10.004.

Behling H, Pillar VD, Müller SC and Overbeck GE (2007b) Late-Holocene fire history in a forest-grassland mosaic in southern Brasil: Implications for conservation. *Applied Vegetation Science* 10(1): 81–90: doi:10.1111/j.1654-109X.2007.tb00506.x.

Behling H, Pillar VD, Orlóci L and Bauermann SG (2004) Late Quaternary Araucaria forest, grassland (Campos), fire and climate dynamics, studied by high-resolution pollen, charcoal and multivariate analysis of the Cambará do Sul core in southern Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology* 203(3-4): 277–297: doi:10.1016/S0031-0182(03)00687-4.

Behling H and Safford HD (2009) Late-glacial and Holocene vegetation, climate and fire dynamics in the Serra dos Órgãos, Rio de Janeiro State, southeastern Brazil: Late Quaternary environmental dynamics. *Global Change Biology* 16(6): 1661–1671: doi:10.1111/j.1365-2486.2009.02029.x.

Berger A and Loutre MF (1991) Insolation values for the climate of the last 10 million years. *Quaternary Science Reviews* 10(4): 297–317: doi:10.1016/0277-3791(91)90033-Q.

Bespalez E (2009) Levantamento arqueológico e etnoarqueologia na aldeia Lalima, Miranda/MS: um estudo sobre a trajetória histórica da ocupação indígena regional. São Paulo, Universidade de São Paulo.

Bigarella JJ (1949) Nota prévia sobre a composição dos sambaquis do Paraná e Santa Catarina. *Arquivos de Biologia e Tecnologia* 4: 95–106.

Bona IAT (2006) Estudo de assinaturas químicas em cerâmica da tradição Tupiguarani da região central do estado do Rio Grande do Sul, Brasil. São Paulo, Universidade de São Paulo.

Bonomo M, Angrizani RC, Apolinaire E and Noelli FS (2015) A model for the Guaraní expansion in the La Plata Basin and littoral zone of southern Brazil. *Quaternary International* 356: 54–73.

Bonomo M, Politis G and Gianotti C (2011) Montículos, jerarquía social y horticultura en las sociedades indígenas del delta del Río Paraná (Argentina). *Latin American Antiquity* 22(3): 297–333.

Brochado JJJP (1969) Pesquisas arqueológicas nos vales do Ijuí e do Jacuí. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 13: 31–62.

Brochado JJJP (1971) Expansão das pesquisas arqueológicas nos vales do Jacuí e Ibicuí-Mirim. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 15: 11–36.

Brochado JJJP (1973) Migraciones que difundieron la tradicion alfarera Tupí-Guaraní. *Relaciones de la Sociedad Argentina de Antropología* 7: 7–39.

Brochado JJJP (1984) An ecological model of the spread of pottery and agriculture into eastern South America. PhD Dissertation, Urbana-Champaign, University of Illinois.

Brochado JJJP, Calderón V, Chmyz I, Evans C, Maranca S, Meggers BJ, et al. (1969) Arqueologia Brasileira em 1968. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 12.

Burbridge RE, Mayle FE and Killeen TJ (2004) Fifty-thousand-year vegetation and climate history of Noel Kempff Mercado National Park, Bolivian Amazon. *Quaternary Research* 61(2): 215–230: doi:10.1016/j.yqres.2003.12.004.

Burn MJ, Mayle FE and Killeen TJ (2010) Pollen-based differentiation of Amazonian rainforest communities and implications for lowland palaeoecology in tropical South America. *Palaeogeography, Palaeoclimatology, Palaeoecology* 295(1–2): 1–18: doi:10.1016/j.palaeo.2010.05.009.

Bush MB, Silman MR, de Toledo MB, Listopad C, Gosling WD, Williams C, et al. (2007a) Holocene fire and occupation in Amazonia: records from two lake districts. *Philosophical Transactions of the Royal Society B: Biological Sciences* 362(1478): 209–218: doi:10.1098/rstb.2006.1980.

Bush MB, Silman MR and Listopad CMCS (2007b) A regional study of Holocene climate change and human occupation in Peruvian Amazonia: Amazonian climate change and settlement. *Journal of Biogeography* 34(8): 1342–1356: doi:10.1111/j.1365-2699.2007.01704.x.

Bush MB, Silman MR and Urrego DH (2004) 48,000 Years of Climate and Forest Change in a Biodiversity Hot Spot. *Science* 303(5659): 827–829: doi:10.1126/science.1090795.

Calegari MR, Madella M, Vidal-Torrado P, Pessenda LCR and Marques FA (2013) Combining phytoliths and δ13C matter in Holocene palaeoenvironmental studies of tropical soils: An example of an Oxisol in Brazil. *Quaternary International* 287: 47–55: doi:10.1016/j.quaint.2011.11.012.

Cano N, Machado NTG, Rocca R, Genaro R, Munita C and Watanabe S (2012) TL dating of pottery fragments from four archaeological sites in Taquari Valley, Brazil. *Radiation Effects and Defects in Solids* 167(12): 947–953.

Carle MB (2002) Investigação arqueológica em Rio Grande: uma proposta da ocupação Guarani pré-histórica no Rio Grande do Sul. Porto Alegre, PUCRS.

Carle MB and Silva OP (2007) Salvamento arqueológico LT 525KV Ivaiporã – Londrina: sítio cerâmico João Batista – acesso a torre 67. paper presented at the XIV Congresso da SAB. SAB.

Carson JF, Watling J, Mayle FE, Whitney BS, Iriarte J, Prümers H, et al. (2015) Pre-Columbian land use in the ring-ditch region of the Bolivian Amazon. *The Holocene* 25(8): 1285–1300: doi:10.1177/0959683615581204.

Carson JF, Whitney BS, Mayle FE, Iriarte J, Prumers H, Soto JD, et al. (2014) Environmental impact of geometric earthwork construction in pre-Columbian Amazonia. *Proceedings of the National Academy of Sciences* 111(29): 10497–10502: doi:10.1073/pnas.1321770111.

Carvalho do Amaral PG, Fonseca Giannini PC, Sylvestre F and Ruiz Pessenda LC (2012) Paleoenvironmental reconstruction of a Late Quaternary lagoon system in southern Brazil (Jaguaruna region, Santa Catarina state) based on multi-proxy analysis. *Journal of Quaternary Science* 27(2): 181–191: doi:10.1002/jqs.1531.

Castillo A (2004) Excavación y Museo: profundizando en el conocimiento de los grupos ceramistas del litoral (Río Negro, Uruguay). In: Beovide L, Barreto I and Curbelo C (eds) *La Arqueología Uruguaya ante los desafíos del Nuevo Siglo*. Montevideo.

Chmyz I (1967) Dados parciais sobre a arqueologia do Vale do Rio Paranapanema. *Publicaçoes Avulsas do Museu Paraense Emilio Goeldi* 6: 59–78.

Chmyz I (1968) Novas perspectivas da arqueologia Guarani no estado do Paraná. *Pesquisas: Antropologia* 18: 171–189.

Chmyz I (1969) Dados parciais sobre a arqueologia do vale do rio Ivaí. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 10: 95–118.

Chmyz I (1974) Dados arqueológicos do baixo Rio Paranapanema e do alto Rio Paraná. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 26: 67–90.

Chmyz I (1976) Arqueologia e história da vila espanhola de Ciudad Real de Guairá. *Cadernos de Arqueologia, Museu de Arqueologia e Artes Populares de Paranaguá* 1: 7–103.

Chmyz I (1983) *Sétimo relatório do Projeto Arqueológico Itaipu*. Curitiba: Itaipu/IPHAN.

Chmyz I (2008) *Relatório técnico final sobre o Projeto de Salvamento Arqueológico efetuado na área diretamente afetada pela LT kV 750 Ivaiporã-Itaberá III*. Curitiba: CEPA.

Chmyz I and Chmyz JC (1986) Datações radiométricas em áreas de salvamento arqueológico do Estado do Paraná. *Revista do CEPA* 5: 69–77.

Cigliano ME (1968) Investigaciones arqueológicas en el río Uruguay medio y la costa NE de la provincia de Buenos Aires. *Pesquisas: Antropologia* 18: 5–9.

Cohen MCL, Rossetti DF, Pessenda LCR, Friaes YS and Oliveira PE (2014) Late Pleistocene glacial forest of Humaitá—Western Amazonia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 415: 37–47: doi:10.1016/j.palaeo.2013.12.025.

Coirolo AD (1990) Prehistoria del Uruguay: clasificación de las formas de los recipientes cerámicos. *Dedalo* 28: 109–145.

Corrêa AA (2009) Tetama nas Matas Mineiras: sítios Tupi na microrregião de Juiz de Fora - MG. São Paulo, Universidade de São Paulo.

Corrêa AA (2014) Pindorama de Mboîa e Îakaré: continuidade e mudança na trajetória das populações Tupi. São Paulo, Universidade de São Paulo.

Cox P (2001) *Description of the TRIFFID dynamic global vegetation model: Hadley Centre Technical Note 24*. .

Cruz FW, Burns SJ, Karmann I, Sharp WD, Vuille M, Cardoso AO, et al. (2005) Insolation-driven changes in atmospheric circulation over the past 116,000 years in subtropical Brazil. *Nature* 434(7029): 63–66: doi:10.1038/nature03365.

Cruz FW, Vuille M, Burns SJ, Wang X, Cheng H, Werner M, et al. (2009) Orbitally driven east–west antiphasing of South American precipitation. *Nature Geoscience* 2(3): 210–214: doi:10.1038/ngeo444.

Dee DP, Uppala SM, Simmons AJ, Berrisford P, Poli P, Kobayashi S, et al. (2011) The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quarterly Journal of the Royal Meteorological Society* 137(656): 553–597: doi:10.1002/qj.828.

Dias AS and Silva SB (2013) Seguindo o fluxo do tempo, trilhando o Caminho das Águas: Territorialidade Guarani na região do Lago Guaíba. *Revista de Arqueologia* 26: 56–71.

Dickau R, Whitney BS, Iriarte J, Mayle FE, Soto JD, Metcalfe P, et al. (2013) Differentiation of neotropical ecosystems by modern soil phytolith assemblages and its implications for palaeoenvironmental and archaeological reconstructions. *Review of Palaeobotany and Palynology* 193: 15–37: doi:10.1016/j.revpalbo.2013.01.004.

Duarte GM (1972) Distribuição e localização de sítios arqueológicos do tipo sambaqui na Ilha de Santa Catarina. *Anais do Museu de Antropologia* 4: 31–60.

Dümig A, Schad P, Rumpel C, Dignac M-F and Kögel-Knabner I (2008) Araucaria forest expansion on grassland in the southern Brazilian highlands as revealed by 14C and δ13C studies. *Geoderma* 145(1-2): 143–157: doi:10.1016/j.geoderma.2007.06.005.

Essery RLH, Best MJ, Betts RA, Cox PM and Taylor CM (2003) Explicit Representation of Subgrid Heterogeneity in a GCM Land Surface Scheme. *Journal of Hydrometeorology* 4(3): 530–543: doi:10.1175/1525-7541(2003)004<0530:EROSHI>2.0.CO;2.

Faccio NB (1992) O Estudo do Sítio Arqueológico Alvim no Contexto do Projeto Paranapanema. São Paulo, Universidade de São Paulo.

Faccio NB (1998) Arqueologia do Cenário das Ocupações Horticultoras da Capivara, Baixo Paranapanema, SP. São Paulo, Universidade de São Paulo.

Farias DSE and Kneip A (eds) (2010) *Panorama Arqueologico de Santa Catarina*. Palhoça: Editora UNISUL.

Farías Gluchy ME (2005) El guaraní arqueológico meridional: entre el axioma y la heterodoxia. Porto Alegre, PUCRS.

Fiegenbaum J (2009) Um Assentamento Tupiguarani no Vale do Taquari/RS. São Leopoldo, Unisinos.

Garcia MJ, De Oliveira PE, de Siqueira E and Fernandes RS (2004) A Holocene vegetational and climatic record from the Atlantic rainforest belt of coastal State of São Paulo, SE Brazil. *Review of Palaeobotany and Palynology* 131(3-4): 181–199: doi:10.1016/j.revpalbo.2004.03.007.

Gaulier P (2001) Ocupação pré-histórica Guarani no município de Porto Alegre, RS: considerações preliminares e primeira datação do sítio arqueológico RS-71-C da Ilha Francisco Manoel. *Revista de Arqueologia* 14/15: 57–73.

Gessert S, Iriarte J, Ríos RC and Behling H (2011) Late Holocene vegetation and environmental dynamics of the Araucaria forest region in Misiones Province, NE Argentina. *Review of Palaeobotany and Palynology* 166(1-2): 29–37: doi:10.1016/j.revpalbo.2011.04.006.

Goldmeier V and Schmitz PI (1983) *Sítios arqueológicos do Rio Grande do Sul: fichas de registro existentes no Instituto Anchietano de Pesquisas, São Leopoldo, RS*. São Leopoldo: IAP.

Gordon C, Cooper C, Senior CA, Banks H, Gregory JM, Johns TC, et al. (2000) The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments. *Climate Dynamics* 16(2-3): 147–168: doi:10.1007/s003820050010.

Gosling WD, Mayle FE, Tate NJ and Killeen TJ (2005) Modern pollen-rain characteristics of tall terra firme moist evergreen forest, southern Amazonia. *Quaternary Research* 64(3): 284–297: doi:10.1016/j.yqres.2005.08.008.

Gouveia SEM, Pessenda LC., Aravena R, Boulet R, Scheel-Ybert R, Bendassoli J., et al. (2002) Carbon isotopes in charcoal and soils in studies of paleovegetation and climate changes during the late Pleistocene and the Holocene in the southeast and centerwest regions of Brazil. *Global and Planetary Change* 33(1-2): 95–106: doi:10.1016/S0921-8181(02)00064-4.

Heckenberger M, Neves EG and Petersen J (1998) De onde surgem os modelos? As origens e expansões Tupi na Amazônia Central. *Revista de Antropologia* 41(1): 69–98.

Hilbert K (1999) Arqueologia guarani na região de Guaíba - RS. paper presented at the X Reunião Científica da Sociedade de Arqueologia Brasileira. SAB.

Hogg AG, Hua Q, Blackwell PG, Niu M, Buck CE, Guilderson TP, et al. (2013) Shcal13 Southern Hemisphere Calibration, 0-50,000 Years Cal Bp. *Radiocarbon* 55(4): 1889–1903.

Hurt WR (1974) The interrelationship between the natural environment and four sambaquis, coast of Santa Catarina, Brazil. *Occasional Papers and Monographs, University of Indiana Museum* 1.

Iriarte J (2006) Vegetation and climate change since 14,810 14C yr B.P. in southeastern Uruguay and implications for the rise of early Formative societies. *Quaternary Research* 65(1): 20–32: doi:10.1016/j.yqres.2005.05.005.

Jeske-Pieruschka V and Behling H (2012) Palaeoenvironmental history of the Sao Francisco de Paula region in southern Brazil during the late Quaternary inferred from the Rincao das Cabritas core. *The Holocene* 22(11): 1251–1262: doi:10.1177/0959683611414930.

Jeske-Pieruschka V, Pillar VD, De Oliveira MAT and Behling H (2013) New insights into vegetation, climate and fire history of southern Brazil revealed by a 40,000 year environmental record from the State Park Serra do Tabuleiro. *Vegetation History and Archaeobotany* 22(4): 299–314: doi:10.1007/s00334-012-0382-y.

Jones HT, Mayle FE, Pennington RT and Killeen TJ (2011) Characterisation of Bolivian savanna ecosystems by their modern pollen rain and implications for fossil pollen records. *Review of Palaeobotany and Palynology* 164(3–4): 223–237: doi:10.1016/j.revpalbo.2011.01.001.

Kashimoto EM (1997) Variáveis ambientais e arqueologia no Alto Paraná. São Paulo, Universidade de São Paulo.

Kashimoto EM (2007) O alto curso do rio Paraná: fronteiras ambientais e arqueológicas. São Paulo, Universidade de São Paulo.

Kashimoto EM and Martins GR (2008) A problemática arqueológica da Tradição cerâmica Tupiguarani no Mato Grosso do Sul. In: Prous A and Lima TA (eds) *Os ceramistas tupiguarani*. Belo Horizonte: Sigma, 149–178.

Kreutz MR (2008) O contexto ambiental e as primeiras ocupações humanas no Vale do Taquari. Lajeado, UNIVATES.

Lavina R (2000) *Projeto de salvamento arqueológico da rodovia interpraias (trecho Morro dos Conventos - Lagoa dos Esteves): relatório final*. Criciúma: UNESC.

Leal MG and Lorscheitter ML (2007) Plant succession in a forest on the Lower Northeast Slope of Serra Geral, Rio Grande do Sul, and Holocene palaeoenvironments, Southern Brazil. *Acta Botanica Brasilica* 21(1): 1–10.

Ledru M-P, Mourguiart P and Riccomini C (2009) Related changes in biodiversity, insolation and climate in the Atlantic rainforest since the last interglacial. *Palaeogeography, Palaeoclimatology, Palaeoecology* 271(1-2): 140–152: doi:10.1016/j.palaeo.2008.10.008.

Ledru M-P, Rousseau D-D, Cruz FW, Riccomini C, Karmann I and Martin L (2005) Paleoclimate changes during the last 100,000 yr from a record in the Brazilian Atlantic rainforest region and interhemispheric comparison. *Quaternary Research* 64(3): 444–450: doi:10.1016/j.yqres.2005.08.006.

Lino JT (2007) Arqueologia Guarani na bacia hidrográfica do rio Araranguá, Santa Catarina. Porto Alegre, UFRGS.

Long A (1965) Smithsonian Institution radiocarbon measurements II. *Radiocarbon* 7: 245–256.

Long A and Mielke J (1967) Smithsonian Institution radiocarbon measurements IV. *Radiocarbon* 6: 368–381.

Loponte D, Acosta A, Capparelli I and Pérez M (2011) La arqueología guaraní en el extremo meridional de la cuenca del Plata. In: Loponte D and Acosta A (eds) *Arqueología Tupiguaraní*. Buenos Aires: Instituto Nacional de Antropología y Pensamiento Latinoamericano, 111–154.

Loulergue L, Schilt A, Spahni R, Masson-Delmotte V, Blunier T, Lemieux B, et al. (2008) Orbital and millennial-scale features of atmospheric CH4 over the past 800,000 years. *Nature* 453(7193): 383–386: doi:10.1038/nature06950.

Macedo RB, Souza PA, Bauermann SG and Bordignon SAL (2010) Palynological analysis of a late Holocene core from Santo Antônio da Patrulha, Rio Grande do Sul, Southern Brazil. *Anais da Academia Brasileira de Ciências* 82(3): 731–745: doi:10.1590/S0001-37652010000300020.

Martins GR, Kashimoto EM and Tatumi SH (1999) Datações arqueológicas em Mato Grosso do Sul. *Revista do Museu de Arqueologia e Etnologia* 9: 73–93.

Mauricio DF (2008) As vasilhas cerâmicas do sítio arqueológico SC-MA-01 do município de Laguna - SC. Tubarão, UNISUL.

Mayle FE, Burbridge RE and Killeen TJ (2000) Millennial-Scale Dynamics of Southern Amazonian Rain Forests. *Science* 290(5500): 2291–2294: doi:10.1126/science.290.5500.2291.

Mielke J and Long A (1969) Smithsonian Institution radiocarbon measurements V. *Radiocarbon* 11(1): 163–182.

Milheira RG (2008) Território e estratégia de assentamento Guarani na planície sudoeste da Laguna dos Patos e Serra do Sudeste - RS. São Paulo, Universidade de São Paulo.

Milheira RG (2010) Arqueologia Guarani no Litoral Sul-Catarinense: História e Território. São Paulo, Universidade de São Paulo.

Milheira RG and DeBlasis P (2011) O território guarani no litoral sulcatarinense: ocupação e abandono no limiar do período colonial. *Revista de Arqueología Americana* 29: 147–182.

Miller ET (1967) Pesquisas Arqueológicas Efetuadas no Nordeste do Rio Grande do Sul. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 6: 15–38.

Miller ET (1969) Pesquisas arqueológicas efetuadas no noroeste do Rio Grande do Sul. *Publicações Avulsas do Museu Paraense Emilio Goeldi* 10: 33–54.

Miller ET (1971) Pesquisas Arqueológicas Efetuadas no Planalto Meridional, Rio Grande do Sul (Rios Uruguai, Pelotas e das Antas). *Publicações Avulsas do Museu Paraense Emilio Goeldi* 15: 37–71.

Miller ET (2009) A Cultura Cerâmica do Tronco Tupí no alto Ji-Paraná, Rondônia, Brasil: Algumas Reflexões Teóricas, Hipotéticas e Conclusivas. *Revista Brasileira de Linguística Antropológica* 1(1): 35–136.

Moraes C de P and Neves EG (2012) O ano 1000: adensamento populacional, interação e conflito na Amazônia Central. *Amazônica-Revista de Antropologia* 4(1): 122–148.

Morais JL (1995) Salvamento arqueológico na área de influência da PCH Moji-Guaçu. *Revista do Museu de Arqueologia e Etnologia* 5: 77–98.

Morais JL (1999) *Projeto Paranapanema: Programa de Pesquisas Arqueológicas da Bacia do Paranapanema, Estado de São Paulo*. .

Morais JL (2000) Tópicos de arqueologia da paisagem. *Revista do Museu de Arqueologia e Etnologia* 10: 3–30.

Morais JL (2001) *Salvamento Arqueológico da UHE Piraju*. .

Morrás H, Moretti L, Píccolo G and Zech W (2009) Genesis of subtropical soils with stony horizons in NE Argentina: Autochthony and polygenesis. *Quaternary International* 196(1-2): 137–159: doi:10.1016/j.quaint.2008.07.001.

Mujica JI (1995a) Primeras aproximaciones sobre el uso del espacio abierto en una aldea guaraní prehispánica. paper presented at the XI Congreso Nacional de Arqueología Argentina, 123–141.

Mujica JI (1995b) Informe de dos sitios arqueológicos guaraní en la provincia de Corrientes, Argentina. paper presented at the XX Encuentro de Geohistoria Regional, 119–127.

Naue G (1973) Dados sobre o estudo dos cerritos na área meridional da lagoa dos Patos, Rio Grande, Rio Grande do Sul. *Revista Veritas* 71(3): 246–269.

Neves EG (2010) A Arqueologia da Amazônia Central e as classificações na Arqueologia Amazônica. In: Pereira E and Guapindaia V (eds) *Arqueologia Amazônica*. Belém: Museu Paranaense Emilio Goeldi, 561–579.

Noelli FS (1999) A ocupação humana na Região Sul do Brasil: Arqueologia, debates e perspectivas-1872-2000. *Revista USP* 44: 218–269.

Oliveira T (2010) Estudo comparativo dos sambaquis Caipora, Lageado e Jaboticabeira I: Interpretações acerca da mudança de material construtivo ao longo do tempo. São Paulo, Universidade de São Paulo.

Pallestrini L (1975) Interpretação das estruturas arqueológicas em sítios do Estado de São Paulo. São Paulo, Universidade de São Paulo.

Pallestrini L (1988) Projeto Paranapanema: Sítio Arqueológico Nunes, Estado de São Paulo. *Revista do Museu Paulista* 33.

Parrenin F, Barnola J-M, Beer J, Blunier T, Castellano E, Chappellaz J, et al. (2007) The EDC3 chronology for the EPICA Dome C ice core. *Climate of the Past* 3(3): 485–497: doi:10.5194/cp-3-485-2007.

Pärssinen M (2005) Quando começou, realmente, a expansão guarani em direção às Serras Andinas Orientais? *Revista de Arqueologia* 18: 51–66.

Peltier WR (2004) GLOBAL GLACIAL ISOSTASY AND THE SURFACE OF THE ICE-AGE EARTH: The ICE-5G (VM2) Model and GRACE. *Annual Review of Earth and Planetary Sciences* 32(1): 111–149: doi:10.1146/annurev.earth.32.082503.144359.

Pessenda LCR (2004) Holocene fire and vegetation changes in southeastern Brazil as deduced from fossil charcoal and soil carbon isotopes. *Quaternary International* 114(1): 35–43: doi:10.1016/S1040-6182(03)00040-5.

Pessenda LCR, Boulet R, Aravena R, Rosolen V, Gouveia SEM, Ribeiro AS, et al. (2001) Origin and dynamics of soil organic matter and vegetation changes during the Holocene in a forest-savanna transition zone, Brazilian Amazon region. *The Holocene* 11(2): 250–254: doi:10.1191/095968301668898509.

Pessenda LCR, Gouveia SEM, Gomes BM, Aravena R, Ribeiro AS and Boulet R (1998) The carbon isotope record in soils along a forest-cerrado ecosystem transect: implications for vegetation changes in the Rondonia state, southwestern Brazilian Amazon region. *The Holocene* 8(5): 599–603: doi:10.1191/095968398673187182.

Pessenda LCR, Saia SEMG, Gouveia SEM, Ledru M-P, Sifeddine A, Amaral PGC, et al. (2010) Last millennium environmental changes and climate inferences in the Southeastern Atlantic forest, Brazil. *Anais da Academia Brasileira de Ciências* 82(3): 717–729: doi:10.1590/S0001-37652010000300019.

Pessenda LCR, Vidotto E, De Oliveira PE, Buso AA, Cohen MCL, Rossetti D de F, et al. (2012) Late Quaternary vegetation and coastal environmental changes at Ilha do Cardoso mangrove, southeastern Brazil. *Palaeogeography, Palaeoclimatology, Palaeoecology* 363-364: 57–68: doi:10.1016/j.palaeo.2012.08.014.

Petit JR, Jouzel J, Raynaud D, Barkov NI, Barnola J-M, Basile I, et al. (1999) Climate and atmospheric history of the past 420,000 years from the Vostok ice core, Antarctica. *Nature* 399(6735): 429–436: doi:10.1038/20859.

Piazza WF (1969) Notícia Arqueológica do Vale do Uruguai. *Publicações Avulsas do Museu Paraense Emílio Goeldi* 10: 55–57.

Pope VD, Gallani ML, Rowntree PR and Stratton RA (2000) The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3. *Climate Dynamics* 16(2-3): 123–146: doi:10.1007/s003820050009.

Poujade RA (1994) Mapa arqueológico de la provincia de Misiones. Asunción: Universidad Nacional de Misiones, Entidad Binacional Yacyretá.

Rebellato L and Woods WI (2012) A review of the Tupi expansion in the Amazon. In: Crawford MH and Campbell BC (eds) *Causes and Consequences of Human Migration: An Evolutionary Perspective*. Cambridge: Cambridge University Press, 436–448.

Reese CA, Liu KB and Thompson LG (2013) An ice-core pollen record showing vegetation response to Late-glacial and Holocene climate changes at Nevado Sajama, Bolivia. *Annals of Glaciology* 54(63): 183–190: doi:10.3189/2013AoG63A375.

Ribeiro PAM (1968) Os sítios arqueológicos do vale do rio Caí. *Pesquisas: Antropologia* 18: 153–169.

Ribeiro PAM (1974) Primeiras datações pelo método C14 para o vale do Caí, Rio Grande do Sul. *Revista do CEPA* 1: 16–22.

Ribeiro PAM (1991) Arqueologia do vale do rio Pardo, Rio Grande do Sul, Brasil. *Revista do CEPA* 18(21): 1–184.

Ribeiro PAM, Ribeiro CT, Silveira I and Klamt SC (1986) Levantamentos arqueológicos nos altos vales dos rios Camaquã e Irapuã, RS, Brasil. *Revista do CEPA* 15: 41–70.

Rodríguez JA (1997) Investigaciones arqueológicas en Yacyretá (Corrientes-Argentina). *Jornadas de Antropología de la Cuenca del Plata* 3: 41–47.

Rodríguez JA (2004) El proceso de migración y dispersión de la tradición tupiguaraní en la Cuenca del Plata. paper presented at the XV congreso Nacional de Arqueología Argentina. Universidad de Río Cuarto, 112.

Rodríguez JA (2009) La ocupación (poblamiento) del norte de Corrientes (Argentina) por fase de la Tradición Tupiguaraní. In: Meggers BJ (ed) *Arqueologia interpretativa. O método quantitativo para o establecimento de seqüências cerâmicas: estudos de casos*. Porto Nacional: UNITINS, 49–62.

Rogge JH (2005) Fenômenos de fronteira: um estudo das situações de contato entre portadores das tradições cerâmicas pré-históricas no Rio Grande do Sul. *Pesquisas: Antropologia* 62: 9–119.

Rohr JA (1969) Sítios arqueológicos do município sul-catarinense de Jaguaruna. *Pesquisas: Antropologia* 22: 1–37.

Rowe HD, Dunbar RB, Mucciarone DA, Seltzer GO, Baker PA and Fritz S (2002) Insolation, Moisture Balance and Climate Change on the South American Altiplano Since the Last Glacial Maximum. *Climatic Change* 52(1-2): 175–199: doi:10.1023/A:1013090912424.

Ruiz Pessenda LC, De Oliveira PE, Mofatto M, de Medeiros VB, Francischetti Garcia RJ, Aravena R, et al. (2009) The evolution of a tropical rainforest/grassland mosaic in southeastern Brazil since 28,000 14C yr BP based on carbon isotopes and pollen records. *Quaternary Research* 71(3): 437–452: doi:10.1016/j.yqres.2009.01.008.

Saia SEMG, Pessenda LCR, Gouveia SEM, Aravena R and Bendassolli JA (2008) Last glacial maximum (LGM) vegetation changes in the Atlantic Forest, southeastern Brazil. *Quaternary International* 184(1): 195–201: doi:10.1016/j.quaint.2007.06.029.

Santi JR (2009) O passado no presente: vestígios pré-coloniais como suporte analítico da paisagem no Vale do Soturno, RS. São Paulo, Universidade de São Paulo.

Scatamacchia MM (1981) Tentativa de caracterização da tradição Tupiguarani. São Paulo, Universidade de São Paulo.

Scatamacchia MM (1990) A tradição policrômica no leste da América do Sul evidenciada pela ocupação Guarani e Tupinambá: fontes arqueológicas e etnohistóricas. São Paulo, Universidade de São Paulo.

Scheer MB, Curcio GR and Roderjan CV (2013) The Late Holocene upper montane cloud forest and high altitude grassland mosaic in the Serra da Igreja, Southern Brazil. *Anais da Academia Brasileira de Ciências* 85(2): 769–783: doi:10.1590/S0001-37652013000200020.

Schmitz PI (1976) Sítios de pesca lacustre em Rio Grande, RS, Brasil. Porto Alegre, PUCRS.

Schmitz PI and Brochado JJJP (1972) Datos para una secuencia cultural del Estado de Rio Grande do Sul, Brasil. *Gabinete de Arqueologia Publicações* 2: 1–20.

Schmitz PI and Sandrin C (2009) O sítio Lagoa dos Índios e o povoamento guarani da planície costeira do Rio Grande do Sul. *Documentos* 11: 89–134.

Sempé MC and Caggiano MA (1995) Las culturas agroalfareras del Alto río Uruguay (Misiones), Argentina. *Revista do Museu de Arqueologia e Etnologia* 5: 27–38.

Sifeddine A, Wirrmann D, Albuquerque ALS, Turcq B, Cordeiro RC, Gurgel MHC, et al. (2004) Bulk composition of sedimentary organic matter used in palaeoenvironmental reconstructions: examples from the tropical belt of South America and Africa. *Palaeogeography, Palaeoclimatology, Palaeoecology* 214(1-2): 41–53: doi:10.1016/j.palaeo.2004.06.012.

Singarayer JS and Burrough SL (2015) Interhemispheric dynamics of the African rainbelt during the late Quaternary. *Quaternary Science Reviews* 124: 48–67: doi:10.1016/j.quascirev.2015.06.021.

Singarayer JS and Valdes PJ (2010) High-latitude climate sensitivity to ice-sheet forcing over the last 120 kyr. *Quaternary Science Reviews* 29(1–2): 43–55: doi:10.1016/j.quascirev.2009.10.011.

Singarayer JS, Valdes PJ, Friedlingstein P, Nelson S and Beerling DJ (2011) Late Holocene methane rise caused by orbitally controlled increase in tropical sources. *Nature* 470(7332): 82–85: doi:10.1038/nature09739.

Spahni R, Chappellaz J, Stocker TF, Loulergue L, Hausammann G, Kawamura K, et al. (2005) Atmospheric science: Atmospheric methane and nitrous oxide of the late pleistocene from Antarctic Ice Cores. *Science* 310(5752): 1317–1321: doi:10.1126/science.1120132.

Stevaux JC (2000) Climatic events during the Late Pleistocene and Holocene in the Upper Parana River: Correlation with NE Argentina and South-Central Brazil. *Quaternary International* 72(1): 73–85: doi:10.1016/S1040-6182(00)00023-9.

Stuckenrath R and Mielke J (1970) Smithsonian Institution radiocarbon measurements VI. *Radiocarbon* 12(1): 193–204.

Stuckenrath R and Mielke J (1972) Smithsonian Institution radiocarbon measurements VII. *Radiocarbon* 14(2): 401–412.

Stuckenrath R and Mielke J (1973) Smithsonian Institution radiocarbon measurements VIII. *Radiocarbon* 15(2): 388–424.

Taylor ZP, Horn SP, Mora CI, Orvis KH and Cooper LW (2010) A multi-proxy palaeoecological record of late-Holocene forest expansion in lowland Bolivia. *Palaeogeography, Palaeoclimatology, Palaeoecology* 293(1-2): 98–107: doi:10.1016/j.palaeo.2010.05.004.

Thompson LG (1998) A 25,000-Year Tropical Climate History from Bolivian Ice Cores. *Science* 282(5395): 1858–1864: doi:10.1126/science.282.5395.1858.

Urrego DH, Bush MB, Silman MR, Niccum BA, De La Rosa P, McMichael CH, et al. (2013) Holocene fires, forest stability and human occupation in south-western Amazonia. *Journal of Biogeography* 40(3): 521–533: doi:10.1111/jbi.12016.

Whitney BS, Dickau R, Mayle FE, Soto JD and Iriarte J (2013) Pre-Columbian landscape impact and agriculture in the Monumental Mound region of the Llanos de Moxos, lowland Bolivia. *Quaternary Research* 80(2): 207–217: doi:10.1016/j.yqres.2013.06.005.

Whitney BS, Dickau R, Mayle FE, Walker JH, Soto JD and Iriarte J (2014) Pre-Columbian raised-field agriculture and land use in the Bolivian Amazon. *The Holocene* 24(2): 231–241: doi:10.1177/0959683613517401.

Whitney BS and Mayle FE (2012) Pediastrum species as potential indicators of lake-level change in tropical South America. *Journal of Paleolimnology* 47(4): 601–615: doi:10.1007/s10933-012-9583-8.

Whitney BS, Mayle FE, Punyasena SW, Fitzpatrick KA, Burn MJ, Guillen R, et al. (2011) A 45kyr palaeoclimate record from the lowland interior of tropical South America. *Palaeogeography, Palaeoclimatology, Palaeoecology* 307(1-4): 177–192: doi:10.1016/j.palaeo.2011.05.012.

Williams JJ, Gosling WD, Brooks SJ, Coe AL and Xu S (2011a) Vegetation, climate and fire in the eastern Andes (Bolivia) during the last 18,000years. *Palaeogeography, Palaeoclimatology, Palaeoecology* 312(1-2): 115–126: doi:10.1016/j.palaeo.2011.10.001.

Williams JJ, Gosling WD, Coe AL, Brooks SJ and Gulliver P (2011b) Four thousand years of environmental change and human activity in the Cochabamba Basin, Bolivia. *Quaternary Research* 76(1): 58–68: doi:10.1016/j.yqres.2011.03.004.

Zech M, Zech R, Morrás H, Moretti L, Glaser B and Zech W (2009) Late Quaternary environmental changes in Misiones, subtropical NE Argentina, deduced from multi-proxy geochemical analyses in a palaeosol-sediment sequence. *Quaternary International* 196(1-2): 121–136: doi:10.1016/j.quaint.2008.06.006.

Zimpel Neto CA (2008) Na direção das periferias extremas da Amazônia: arqueologia na bacia do rio Jiparaná, Rondônia. São Paulo, Universidade de São Paulo.

Zuse S (2009) Os Guarani e a redução jesuítica: tradição e mudança técnica na cadeia operatória de confecção dos artefatos cerâmicos do sítio Pedra Grande e entorno. São Paulo, Universidade de São Paulo.