Quaternary International 289 (2013) 71–77

Contents lists available at SciVerse ScienceDirect

Quaternary International

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

Holocene palaeofires in Neotropics high mountains: The contribution of soil charcoal analysis

E. Allevato [a,*], S. Impagliazzo [a], I. Passariello [b], F. Marzaioli [b], F. Terrasi [b], G. Di Pasquale [a]

[a] *Dipartimento di Arboricoltura Botanica e Patologia Vegetale, Università di Napoli Federico II, Via Università 100, 80055 Portici, Italy*
[b] *CIRCE, Dipartimento di Scienze Ambientali, II Università di Napoli and INNOVA, via Vivaldi 43, 81100 Caserta, Italy*

ARTICLE INFO

Article history:
Available online 29 May 2012

ABSTRACT

The Holocene palaeofires in Southern America has been generally attributed to climate until the middle Holocene and to human activities for later periods. Soil charcoal analysis and extensive AMS dating were carried out on six soil profiles, between 3400 and 3900 m a.s.l. in the Guandera Biological Reserve (Western Cordillera Real, North Ecuador). AMS results showed an ordered stratification of charcoals allowing a fire history reconstruction over the last 11,700 cal BP.

The reported fire occurrences fit well with Holocene global scale arid periods. The association between fires and climate signals suggested a marginal role of humans in the environmental history of the studied area. Here, the human inference started at ca 2500 cal BP, but became considerable only in the last millennium.

1. Introduction

The impact of fire in the Northern Andes has been largely investigated from both ecological and palaeoclimatological perspectives, as well as in relation to human impact. At present, the main proxy for reconstructing fire history has been based on counting charcoal in pollen slides. Up to now, this method did not allow unequivocal assessment of the causes of Holocene fires, and chronological constraint of the beginning of anthropic fires. In northern Peru, fires since 6000 cal BP at Laguna Chochos (Bush et al., 2005) and from 4000 cal BP at Laguna Baja (Hansen and Rodbell, 1995) were considered human-induced. In the south-eastern Ecuadorian Andes, human-induced fires are reported from ca 8000 cal BP at El Tiro-Pass (Niemann and Behling, 2008) and at Laguna Cocha Caranga (Niemann and Behling, 2009). On the other hand, several authors (e.g. Kessler, 2002; Bush et al., 2005) leave open the question whether the charcoal dated before the middle Holocene represents the evidence of either the first human presence or of natural fires related to climatic conditions. In the Guandera Biological Station, western Cordillera Real, northern Ecuador, charcoal influx became significant ca 2000 cal BP, but humans were considered the driving force of fires only from 600 cal BP (Bakker et al., 2008).

Although as a general pattern, palaeofires have been broadly attributed to the climate until the middle Holocene, and afterwards to human activities, the distinction between climate and human-induced fires remains rather uncertain. This is probably also due to the low-resolution of the data in terms both of time and space inferred from counting of charcoal particles in pollen slides (Conedera et al., 2009; Mooney and Tinner, 2011).

At local scales, soil charcoal analysis (SCA, pedoanthracology; Thinon, 1978; Carcaillet and Thinon, 1996) is a valuable approach to investigate local fire history (Payette and Gagnon, 1985; Carcaillet, 1998). This method is based on the anatomical identification and ^{14}C dating of charcoal fragments ($\geq$0.4 mm). It has been successfully applied in the Northern Andes to detect treeline shifts during the Holocene (Di Pasquale et al., 2008) and to reconstruct the fire history during the Pleistocene–Holocene transition (Di Pasquale et al., 2010). This work presents a fire history reconstruction based on SCA for the Holocene, with the major objective of discriminating between human and climatic fires in Guandera region. Data are plotted with two palaeofire records based on sedimentary charcoal sequences at local and regional scale. Subsequently, data are compared with a global synthesis of climate history constructed from proxies unaffected by human impact.

2. Study area

The study area is located on the western Cordillera Real (northern Ecuador), at the Guandera Biological Reserve (Fig. 1) (0° 36′ N, 77° 41′ W). Guandera Biological Reserve includes about 10 km^2 of relatively undisturbed páramo grassland, shrubland and (high) Andean forest. Andean forest, also called upper montane rain forest, is located

---

* Corresponding author.
E-mail address: eallevat@unina.it (E. Allevato).

1040-6182/$ – see front matter © 2012 Elsevier Ltd and INQUA. All rights reserved.
doi:10.1016/j.quaint.2012.05.030

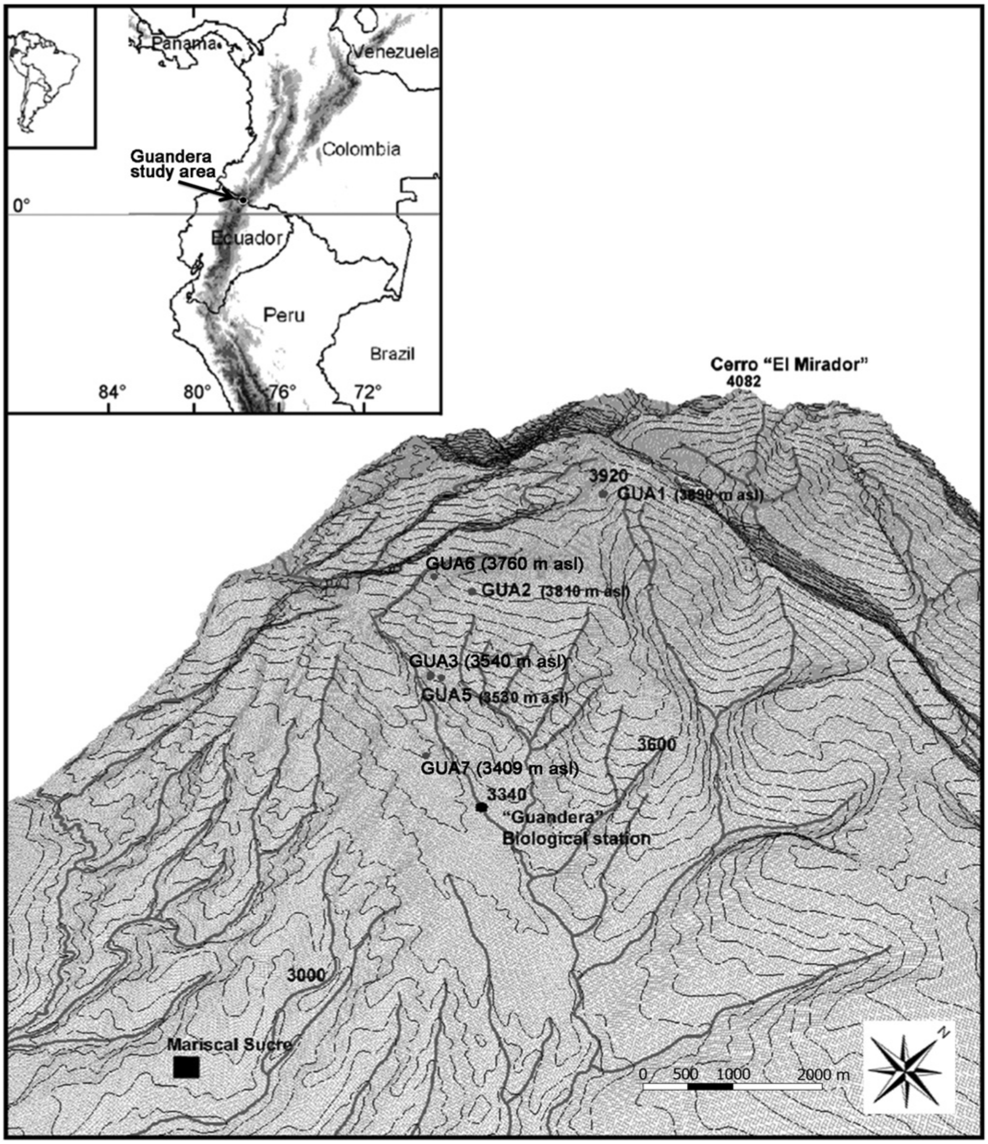

Fig. 1. Study area (inset) and location of sampling points (main map).

between 3300 and ~3500 m a.s.l., ~100 m below the present-day upper forested limit (UFL). A fringe of high Andean forest or Subalpine rain forest extends above this level up to the lower limit of the páramo (Moscol Olivera and Hooghiemstra, 2010). Above 3640 m a.s.l., the prevailing bunchgrass páramo is interrupted by scattered forest islands occurring up to about 3700 m a.s.l. Below 3300 m a.s.l., the area has been almost completely deforested for cattle and agriculture, mainly in the form of fenced meadows and potato cultivation (Moscol Olivera and Cleef, 2009).

The area is characterized by a typical humid tropical alpine climate with strong diurnal, but weak annual temperature fluctuations. Temperature and precipitation values in Guandera were registered for 2002 at 3370 m a.s.l. The daily temperatures ranged between 4 °C and 15 °C; the sum of annual precipitation was ~1700 mm (Bader et al., 2007a, 2007b). The forest soil has an organic upper horizon of 30–100 cm consisting principally of roots, and is classified as Cambisol or Histosol. The páramo soil is a deep and well-developed Andosol (Soil Survey Staff, 1999).

Pàramo can burn well because of fuel abundance due to the large amount of dead plant material dried by the strong insolation levels. In contrast, the cloud forest has a humid microclimate characterized by continuous fog and, therefore, it is unlikely to catch fire (Di Pasquale et al., 2008).

The historical data for this area comes from oral sources reporting human-made fires in the pàramo grassland related to religious/superstitious practices every 3–6 years (Sarmiento and Frolich, 2002).

3. Material and methods

Six soil profiles at Guandera biological station were sampled along a 4 km transect spanning between 3400 m and 3900 m a.s.l (Fig. 1). Soil sampling and charcoal analysis followed Carcaillet and Thinon (1996); detailed soil sampling and charcoal sorting procedure is reported in Di Pasquale et al. (2008). The soil charcoal concentration (SCC – mg charcoal/kg dry soil: ppm) was calculated for each level and in the entire profiles. Identified taxa and SCC are reported exclusively for the dated levels (Table 1).

AMS ^{14}C dating was carried out on 19 charcoal samples (11 of which were previously published in Di Pasquale et al., 2008, 2010) at the Center for Isotopic Research on Cultural and Environmental Heritage (University of Naples 2, Caserta, Italy) (Terrasi et al., 2008)

Table 1

Analysis of soil charcoal fragments from Guandera Biological Station, northern Ecuador. For each dated charcoal, depth of the sampling level, corresponding SCC and list of identified *taxa* are reported. Charcoal ages were obtained by AMS ^{14}C. Calibration was carried out with OxCal v 4.1 (Bronk Ramsey, 2001, 2009) using the IntCal04 calibration curve (Reimer et al., 2004). Reference column refers to previously published dates.

Lab code	Soil profile	Dated layer (cm)	SCC (ppm)	^{14}C BP	Cal BP (2σ) 95.40%	Reference	Identified taxa
DSA345	GUA1	20–40	106	2026 ± 39	2111–1890	Di Pasquale et al., 2008	*Cf. Pernettia prostrata.*
DSA342	GUA1	60–80	9	3692 ± 47	4154–3893	Di Pasquale et al., 2008	*Blechnum.*
DSA341	GUA1	80–108	14	10596 ± 367	13,199–11,318	Di Pasquale et al., 2008	*Pentacalia vaccinoides.*
DSH322	GUA2	50–75	28	2198 ± 20	2310–2148		*Miconia chiorocarpa, Pentacalia vaccinoides, Brachiotum alpinum.*
DSA322	GUA2	75–100	55	4364 ± 51	5260–4837	Di Pasquale et al., 2008	*Diplostehium.*
DSA754	GUA2	100–125	77	7236 ± 32	8160–7977	Di Pasquale et al., 2008	*Pentacalia vaccinoides, Diplostephium.*
DSA313	GUA2	125–150	282	10886 ± 158	13,128–12,551	Di Pasquale et al., 2008	Undet.
DSA312	GUA2	150–195	36	10964 ± 167	13,185–12,582	Di Pasquale et al., 2008	*Pentacalia vaccinoides.*
DSA551	GUA3	170–200	48	10842 ± 46	12,880–12,600	Di Pasquale et al., 2008	*Pentacalia vaccinoides.*
DSH325	GUA3	100–120	4	7003 ± 54	7940–7705		*Pernettia prostrata.*
DSA549	GUA3	120–140	24	5050 ± 30	5901–5726	Di Pasquale et al., 2008	*Pernettia prostrata.*
DSH385	GUA5	25–50	87	2902 ± 22	3142–2959		*Thybaudia parviflora Myrsine andina, Brachiotum alpinum.*
DSH388	GUA5	70–90	72	9664 ± 34	11,199–10,802	Di Pasquale et al., 2010	*Espeletia pycnophylla, Diplostephium cf. floribundum.*
DSH324	GUA6	50–75	56	3066 ± 35	3369–3170		*Loricaria thuyoides, Pentacalia vaccinoides, Blechnum.*
DSH387	GUA6	75–100	8	4102 ± 55	4823–4445		*Loricaria thuyoides, Pentacalia vaccinoides, Blechnum.*
DSH402	GUA6	100–130	37	9902 ± 52	11,601–11,209	Di Pasquale et al., 2010	*Pentacalia vaccinoides.*
DSH327	GUA7	34–50	219	821 ± 18	768–688		*Thybaudia parviflora, Myrsine andina,Miconia, Blechnum, Pentacalia vaccinoides, Espeletia pycnophylla, Brachyotum alpinum.*
DSH389	GUA7	64–87	8	7346 ± 28	8284–8035		*Pentacalia vaccinoides, Weinmannia.*
DSH321	GUA7	87–115	37	3552 ± 36	3964–3719		*Pentacalia vaccinoides, Pernettya prostrata.*

and at Dynamitron Tandem Laboratory (University of Bochum, Germany) (Lubritto et al., 2004).

The obtained radiocarbon ages were calibrated using OxCal v 4.1. program (Bronk Ramsey, 2001, 2009), considering the INTCAL04 calibration curve (Reimer et al., 2004) acceptable for the calibration (Table 1). Only 16 dates with calibration intervals falling after 11,700 cal BP have been considered for the reconstruction of the Holocene fire history in Guandera. Four pre-Holocene dates were reported exclusively in order to discuss the charcoal time-stratification in the soils. SCC bars of the dated level were plotted on a cal BP time scale corresponding to the maximum probability. Each bar reflects a fire event chronologically constrained by the ^{14}C date, but each event can be embedded in a fire period of unknown duration. The term "fire phase" is used where fire events have contiguous or overlapping dating intervals.

4. Results

Charcoals were found at all depths in all soil profiles, except for the organic layers of the forest soils (level I, GUA7; levels I–III, GUA3) which, consisting mostly of roots, were unable to retain charcoal fragments. Charcoal ages consistently decreased according to the soil depth, except for two inversions in the soil GUA 3 and GUA 7 sample profiles (Fig. 2).

Fire phases were detected ca 11,000 cal BP (Table 1, Fig. 3) and around 8000 cal BP. More recently, fire events became more frequent between ca 5700 cal BP and ca 2000 cal BP, and a last fire event was identified at 700 cal BP (Table 1, Fig. 3). The SCC ranges between 4 and 219 ppm, reaching higher values in the last 1000 years (Table 1, Fig. 3). Charcoal identification revealed that burned vegetation was pàramo, but with isolated evidence of tree taxa at 3300 and 3040 cal BP, whereas at ca 700 cal BP forest taxa represent unambiguous signals of forest fires (Table 1, Fig. 3).

5. Discussion

5.1. Charcoal time stratification

The age of dated charcoals showed a homogeneous stratification in the soil profiles (Fig. 2) apart from two cases of age inversion in Gua 3 and Gua 7 (Fig. 2). Pedological field observations (e.g. abrupt upper boundaries of the buried soils) seem to suggest that this inversion is not strictly related to reworking by pedofauna. Soil-landscape features such as slope dynamics and soil erosion may better explain the observed inversion. Older soils, corresponding to ancient paleosurfaces in upper slope position, can be eroded and redeposited downslope. This is compatible with the well-known high susceptibility of Andosols to slope processes (e.g. Arnalds et al., 2001; Terribile et al., 2007).

On the other hand, many ^{14}C dates of soil organic matter at Guandera showed a strong age–depth relationship, indicating that these soils can be suitable for palaeoecological research (Tonneijck et al., 2006, 2008). However, if stratification of charcoal particles is fundamental in studies dealing with vegetation changes, the main contribution of SCA, even in the absence of stratification, is to yield spatially precise insights on fire occurrence during the Holocene. Even if charcoal fragments were randomly sampled for dating in a soil profile, they could provide a suitable proxy for reconstruction of fire history (Carcaillet, 2001).

At Guandera, SCC ranged between 4 ppm and 106 ppm (43.5 mean) in all layers where charcoal analysis revealed pàramo vegetation. SCC reaches the highest value (219 ppm) at 730 cal BP, in association with recent forest fires, and thus the higher value of SCC could reflect burning of trees (Fig. 3). Few other SCA studies have previously been carried out, mainly in European alpine environments. The variability in charcoal concentration and in assemblages in neighbouring pits (Touflan and Talon, 2009) highlights the

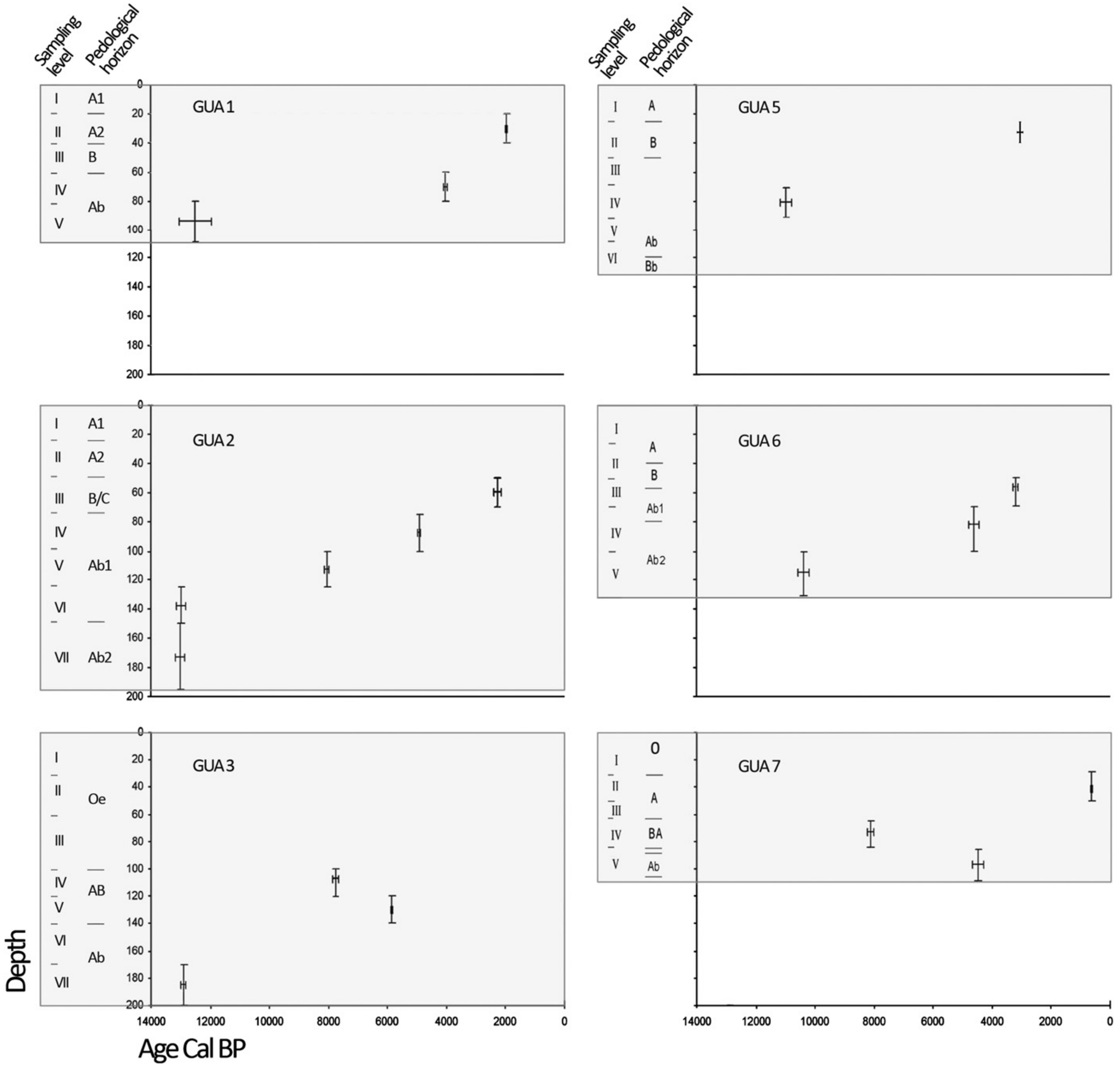

Fig. 2. Depth–age relationships for the studied six soil profiles. Horizontal bars indicate the range of the calibrated dates at 2σ, while vertical bars indicate the thickness of the sampling level to which the dates are applied. Thickness of both pedostratigraphic units and sampling levels are also shown. Dates are expressed in calibrated years BP.

close relationship with both spatial distribution of burnt trees (Payette et al., 2007) and microtopography. The lack of comparable data for high Neotropics makes it hard to understand the significance of the SCC values. In Guandera, the sudden increase of SCC in the last millennium whose anatomical identification reported several forest taxa can be considered as an indicator of human presence, because natural forest fires in Guandera do not occur (Di Pasquale et al., 2008).

5.2. *Holocene palaeofires timing in Guandera*

In the high Northern Andes, the fire history inferred from charcoal particles in pollen slides often shows largely contradictory results. In Ecuador, at Laguna Chorreras (2° 45′ S, 79° 10′ W; 3700 m a.s.l.), more frequent fires were detected in the early-middle Holocene until 4000 cal BP (Hansen et al., 2003). Data from Laguna Cocha Caranga (4° 02′ S, 79° 09′ W; 2710 m a.s.l.) show fires increasing between 7300 and 1200 cal BP (Niemann and Behling, 2009), while at Cerro Toledo (4° 22′ S, 79° 06′ W; 3110 m a.s.l.) fires occur only during the last 1200 years (Brunschön and Behling, 2009). In Peru, the data from Laguna Baja (7° 42′ S, 77° 32′ W; 3575 m a.s.l.) and Laguna Chochos (7° 38′ S, 77° 28′ W; 3285 a.s.l.), reveal regularly occurring fires throughout the Holocene, with slightly higher values during the last 5000 years (Bush et al., 2005).

Changes in fire activity are attributed to climate change or variability, anthropogenic activity, fuels and/or to complex interactions among these variables. Charcoal size and concentration as

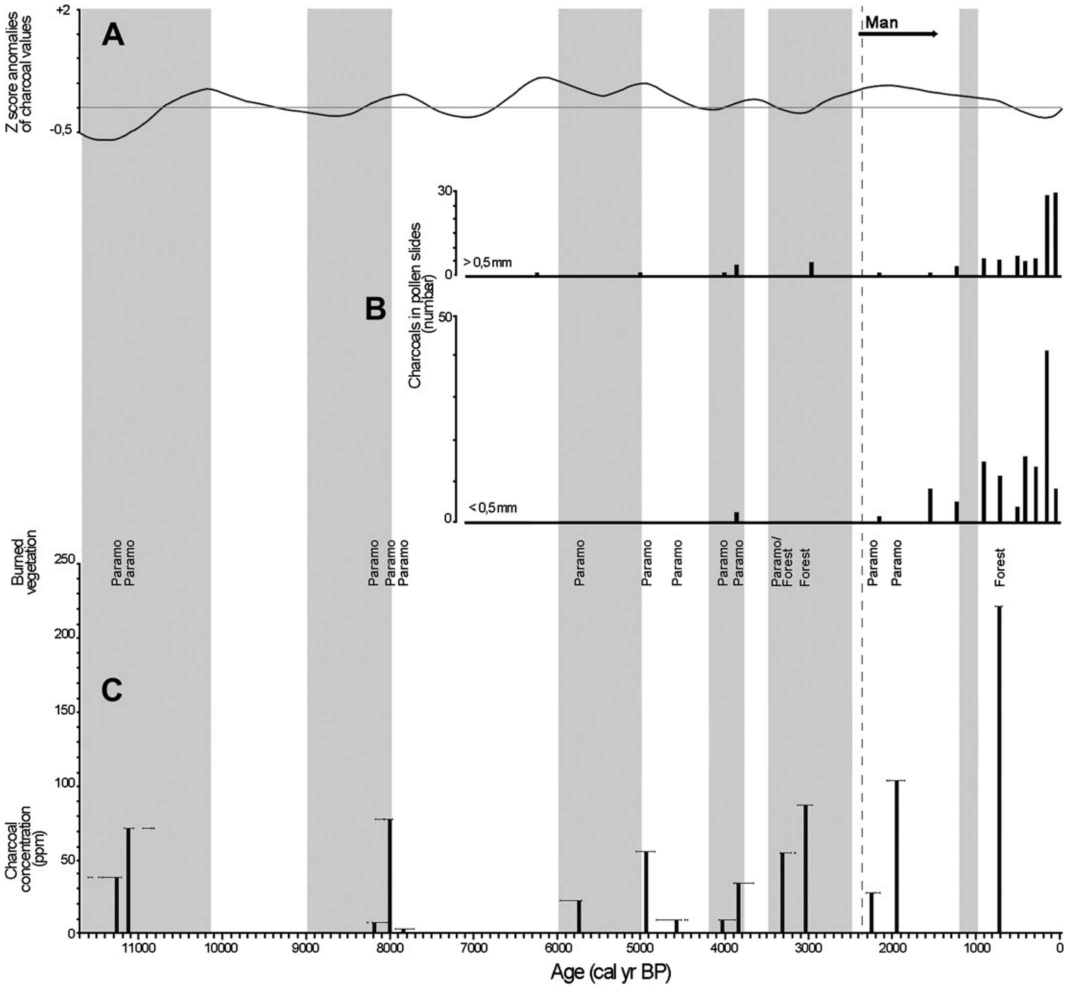

Fig. 3. Comparison of fire history data and climate. Grey bands outline the age intervals of El Abra Stadial (Van't Veer et al., 2000) and the dry tropics RCCs (Mayewski et al., 2004). The dashed line shows the start of man induced fires as inferred by SCA in Guandera. (A) Charcoal records of burned biomass in Neotropics (Power et al., 2010). (B) Charcoal particles in pollen slides from the sediment core G15 in Guandera (Bakker et al., 2008). (C) Burned vegetation type and SCC of soil charcoals in Guandera. The bars are positioned on the max probability age in the calibration intervals, horizontal bars indicate the range of the calibrated dates at 2σ.

well as vegetation changes inferred from paired (associated) pollen analysis represent the interpretative basis for distinguishing between climatic and anthropogenic fires.

With the major objective of discriminating between human and climatic fires in Guandera region, data were tentatively matched with the palaeofire records based on sedimentary charcoal sequences (Bakker et al., 2008) and with the palaeofire activity regional synthesis in tropical America (30°N–30°S) (Power et al., 2010). Then, data were matched with a global synthesis of climate history carried out from proxies unaffected by human impact (Mayewski et al., 2004).

The synthesis work carried out in the Neotropics using 56 charcoal records obtained from the Global Charcoal Database (Fig. 3a), suggests that the Holocene fire activity in this region was associated with periods of high climate variability, including changes of moisture levels and intensification of seasonal droughts (Power et al., 2010). The authors state that additional high-resolution charcoal records would be needed for a better assessment of regional fire-frequency trends. In detail, the increase of fire activity after 11,000 and between ca 10,000 and 8500 cal BP is antiphased in the northern versus southern Neotropics. Biomass burning generally decreased from ca 6000 cal BP to present, with some multi-centennial periods of high fire activity contrasting with the longer trend (Power et al., 2010).

The lack of coherence between the study area data and the Neotropic fires (see also Fig. 3a) is probably due to the fact that this data set includes sites with different environment and biomes, which are characterised by a strongly different human histories and thus different fire histories. Contreras (2010) remarks that human–environment relationships have a long and diverse history in the Andes and stresses the role of fires both in pastoralism and early agriculture. Moreover, among the considered records only about 3% refer to the high Andes environment.

The good match of Guandera fire chronology with Holocene arid periods (Fig. 3) is worthy of note. The second phase of the El Abra stadial (Van der Hammen and Hooghiemstra, 1995; Van't Veer et al., 2000) and four out of five Rapid Climate Changes (RCC) towards arid conditions detected on the global scale by Mayewski et al. (2004) relate well with the local evidence of fire in the same periods. The El Abra is considered the Younger Dryas (YD) equivalent in northern South America, including both the YD and the earliest Holocene until about 9000 BP (ca 10,200 cal BP) (Van't Veer et al., 2000). The same cold and dry period, the Huelmo/Mascardi cold reversal ending at 10,150 ^{14}C B.P. [cal BP 11,400–cal BP 12,074], is also recorded at mid-latitudes in South America (Hajdas et al., 2003).

In Guandera, a first Holocene fire phase (ca. 11,000 cal BP, Fig. 3) occurred in the second phase of the El Abra stadial (Fig. 3), characterised by drier and warmer climate conditions compared to the previous period (Van der Hammen and Hooghiemstra, 1995). In this area, corresponding to the first El Abra phase, a fire-clear period was also detected by SCA (Di Pasquale et al., 2010). In the northern Andes, fire evidence from this same period have been reported from Peru (11,600–10,000 ^{14}C BP; Laguna Baja 3575 m a.s.l., Hansen and Rodbell, 1995) and Ecuador (ca. 10,000 ^{14}C BP; Lake Surucucho 3200 m a.s.l., Colinvaux et al., 1997; ca 13,000 cal BP; Laguna Chorreras 3700 m a.s.l., Hansen et al., 2003), associated with natural ignition during the dry phase (Hansen and Rodbell, 1995).

Later, fire chronology well fits with four out of five global arid RCC events: 9000–8000, 6000–5000, 4200–3800 and 3500–2500 cal BP (Mayewski et al., 2004) (Fig. 3). These RCC were obtained by tuning ~50 globally distributed high-resolution and multiparameter proxy records to the well-dated Greenland Ice Sheet Project Two (GISP2) chemistry series. Most RCC are characterised by tropical aridity, polar cooling and major atmospheric circulation changes.

To date, a synchronicity between palaeofires and arid RCCs has not been detected in Southern America. Such correspondence could be highlighted by the SCA high spatial resolution and by the demonstrated absence of anthropogenic fires until the last 2500 cal BP. In Southern America, despite the weak definition of the signal, the Lake Titicaca level, dropping during the arid RCC, confirms the arid trend in the considered RCC period (Mayewski et al., 2004 and references therein).

In Guandera, fire history inferred by charcoal particles in pollen slides spans only the last six millennia (Bakker et al., 2008). It is coherent with the fire chronology (Fig. 3b). Although these data reveal increasing fire events from ca 2200 BP cal (Fig. 3b), the authors recognized a significant human impact only after ca 600 cal BP. Fires detected between 900 and 500 cal BP have not been considered of local anthropogenic origin, because of both the absence of pollen indicators and the small size of the charcoal particles (Bakker et al., 2008).

The data show a first local fire phase unrelated to a dry period between ca 2500 and 2000 cal BP. Human impact in Guandera could have started in this period, but a clear relation with human pressure increase can be assessed only from 700 cal BP, slightly predating the results from sedimentary charcoal in Guandera (Bakker et al., 2008).

On the other hand, although the first human appearance in southern America is dated to the Pleistocene–Holocene transition (Fiedel, 1999; Gnecco, 2003), the timing of the human colonization in the Andes is poorly known (Jolie et al., 2011). Weak evidence exists on human presence in the high Ecuadorian Cordillera since 2000 years ago (Bellwood, 2005). Fires detected after 2500 cal BP could be the first evidence of the human activity in Guandera, later increasing around 700 cal BP.

6. Conclusion

In this work, sixteen ^{14}C dates of soil charcoal, coming from well time-stratified soils, have produced an interesting hypothesis about the Holocene fire history in the Northern Andes. In this first synthesis of available AMS data, there is good correlation with dry periods reconstructed by other methods. Fire occurrence well fits with age brackets of arid periods at global scale until 2500 cal BP. After this date, fire becomes more frequent and could be related to humans, but soil charcoal records clearly revealed forest fires caused by humans at ca 700 cal BP. The fire history inferred by SCA in Guandera could have a global relevance at least until 2500 cal BP, and only later would it have only a local significance. Further AMS dates of charcoals from both dated and undated soil levels will be done in order to better understand the Holocene fire history of this region and its significance in terms of non-local fire history. Finally, this work calls into question the limitation of SCA due to the absence of charcoal time-stratification in the soils. Based on these data, charcoals are in general time-stratified in soils, providing good potential for reconstruction of local as well as regional fire histories.

Acknowledgements

We thank Prof. Stefano Mazzoleni for his valuable and extensive revision of the first version of our manuscript. We also acknowledge the very useful comments of the referees, which helped us to significantly improve the original manuscript. Special thanks go to the Editor for his kind courtesy in providing final revision of the English form.

References

Arnalds, O., Thorarinsdottir, E.F., Metusalemsson, S., Jonsson, A., Gretarsson, E., Arnason, A., 2001. Soil Erosion in Iceland. Soil Conservation Service and Agricultural Research Institute, Reykjavik, Iceland.

Bader, M.Y., Rietkerk, M., Bregt, A.K., 2007a. Vegetation structure and temperature regimes of tropical alpine treelines. Arctic, Antarctic and Alpine Research 39, 353–364.

Bader, M.Y., van Geloof, I., Rietkerk, M., 2007b. High solar radiation hinders tree establishment above the alpine treeline in northern Ecuador. Plant Ecology Online 191, 33–45.

Bakker, J., Olivera, M.M., Hooghiemstra, H., 2008. Holocene environmental change at the upper forest line in northern Ecuador. The Holocene 18, 877–893.

Bellwood, P., 2005. First Farmers. The Origins of Agricultural Societies. Blackwell, Malden.

Bronk Ramsey, C., 2001. Development of the radiocarbon program OxCal. Radiocarbon 43 (2A), 355–363.

Bronk Ramsey, C., 2009. Bayesian analysis of radiocarbon dates. Radiocarbon 51, 337–360.

Brunschön, C., Behling, H., 2009. Late Quaternary vegetation, fire and climate history reconstructed from two cores at Cerro Toledo, Podocarpus National Park, southeastern Ecuadorian Andes. Quaternary Research 72, 388–399.

Bush, M.B., Hansen, B.C.S., Rodbell, D., Seltzer, G.O., Young, K.R., Leon, B., Silman, M.R., Abbott, M.B., Gosling, W.D., 2005. A 17,000 year history of Andean climatic and vegetation change from Laguna de Chochos, Peru. Journal of Quaternary Science 20, 703–714.

Carcaillet, C., 1998. A spatially precise study of Holocene fire history, climate and human impact within the Maurienne valley, North French Alps. Journal of Ecology 86, 384–396.

Carcaillet, C., 2001. Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS ^{14}C dates. Holocene 11, 231–242.

Carcaillet, C., Thinon, M., 1996. Pedoanthracological contribution to the evolution of the upper treeline in the Maurienne Valley (North French Alps): methodology and preliminary data. Review of Palaeobotany and Palynology 91, 399–416.

Colinvaux, P., Bush, M.B., Steinitz-Kannan, M., Miller, M.C., 1997. Glacial and postglacial pollen records from the Ecuadorian Andes and Amazon. Quaternary Research 48, 69–78.

Conedera, M., Tinner, W., Neff, C., Meurer, M., Dickens, A.F., Krebs, P., 2009. Reconstructing past fire regimes: methods, applications, and relevance to fire management and conservation. Quaternary Science Reviews 28, 435–456.

Contreras, D.A., 2010. Landscape and Environment: insights from the prehispanic Central Andes. Journal of Archaeological Research 18, 241–288.

Di Pasquale, G., Marziano, M., Impagliazzo, S., Lubritto, C., Bader, M., 2008. The Holocene treeline in the northern Andes (Ecuador): first evidence from soil charcoal. Palaeogeography, Palaeoclimatology, Palaeoecology 259, 17–34.

Di Pasquale, G., Impagliazzo, S., Lubritto, C., Marziano, M., Passariello, I., Russo Ermolli, E., 2010. Soil charcoal analysis as a climato-stratigraphical tool: the key case of Cordillera Real, northern Andes. In: Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, vol. 268, pp. 1088–1090.

Fiedel, S.J., 1999. Older than we thought: implications of corrected dates for paleoindians. American Antiquity 64, 95–115.

Gnecco, C., 2003. Against ecological reductionism: Late Pleistocene hunter-gatherers in the tropical forests of northern South America. Quaternary International 109–110, 13–21.

Hajdas, I., Bonani, G., Moreno, P.I., Ariztegui, D., 2003. Precise radiocarbon dating of Late-Glacial cooling in mid-latitude South America. Quaternary Research 59, 70–78.

Hansen, B.C.S., Rodbell, D.T., 1995. A late-glacial/Holocene pollen record from the eastern Andes of Northern Peru. Quaternary Research 44, 216–227.

Hansen, B.C.S., Rodbell, D.T., Seltzer, G.O., Leon, B., Young, K.R., Abbott, M., 2003. Late-glacial and Holocene vegetational history from two sites in the western Cordillera of southwestern Ecuador. Palaeogeography Palaeoclimatology Palaeoecology 194, 79–108.

Jolie, E.A., Lynch, T.F., Geib, P.R., Adovasio, J.M., 2011. Cordage, Textiles, and the Late Pleistocene Peopling of the Andes. Current Anthropology 52, 285–296.

Kessler, M., 2002. The "Polylepis problem": where do we stand? Ecotropica 8, 97–110.

Lubritto, C., Rogalla, D., Rubino, M., Marzaioli, F., Passariello, I., Romano, M., Spadaccini, G., Casa, G., di Leva, A., de Cesare, N., D'Onofrio, A., Gialanella, L., Imbriani, G., Palmieri, A., Roca, V., Rolfs, C., Sabbarese, C., Strieder, F., Schüermann, D., Terrasi, F., 2004. Accelerator mass spectrometry at the 4 MV Dynamitron Tandem in Bochum. Nuclear Instruments and Methods in Physics Research Section B 222, 255–260.

Mayewski, P.A., Rohling, E.E., Curt Stager, J., Karlen, W., Maasch, K.A., David Meeker, L., Meyerson, E.A., Gasse, F., van Kreveld, S., Holmgren, K., Lee-Thorp, J., Rosqvist, G., Rack, F., Staubwasser, M., Schneider, R.R., Steig, E.J., 2004. Holocene climate variability. Quaternary Research 62, 243–255.

Mooney, S.D., Tinner, W., 2011. The analysis of charcoal in peat and organic sediments. Mires and Peat 7, 1–18.

Moscol Olivera, M.C., Cleef, A.M., 2009. Vegetation composition and altitudinal distribution of Andean rain forests in El Angel and Guandera reserves, northern Ecuador. Phytocoenologia 39, 175–204.

Moscol Olivera, M.C., Hooghiemstra, H., 2010. Three millennia upper forest line changes in northern Ecuador: pollen records and altitudinal vegetation distributions. Review of Palaeobotany and Palynology 163, 113–126.

Niemann, H., Behling, H., 2008. Late Quaternary vegetation, climate and fire dynamics inferred from the El Tiro record in the southeastern Ecuadorian Andes. Journal of Quaternary Science 23, 203–212.

Niemann, H., Behling, H., 2009. Late Pleistocene and Holocene environmental change inferred from the Cocha Caranga sediment and soil records in the southeastern Ecuadorian Andes. Palaeogeography, Palaeoclimatology, Palaeoecology 276, 1–14.

Payette, S., Gagnon, R., 1985. Late-Holocene deforestation and tree regeneration in the forest-tundra of Québec. Nature 313, 570–572.

Payette, S., Filion, L., Delwaide, A., 2007. Spatially explicit fire- climate history of the boreal forest–tundra (eastern Canada) over the last 2000 years. Philosophical Transactions of the Royal Society, B 363, 2301–2316.

Power, M.J., Bush, M.B., Behling, H., Horn, S.P., Mayle, F.E., Urrego, D.H., 2010. Paleofire activity in tropical America during the last 21 ka: a regional synthesis based on sedimentary charcoal. PAGES News 18, 73–75.

Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., Blackwell, P.G., Buck, C.E., Burr, G.S., Cutler, K.B., Damon, P.E., Edwards, R.L., Fairbanks, R.G., Friedrich, M., Guilderson, T.P., Hogg, A.G., Hughen, K.A., Kromer, B., McCormac, F.G., Manning, S.W., Ramsey, C.B., Reimer, R.W., Remmele, S., Southon, J.R., Stuiver, M., Talamo, S., Taylor, F.W., van der Plicht, J., Weyhenmeyer, C.E., 2004. IntCal04 terrestrial radiocarbon age calibration, 26–0 ka BP. Radiocarbon 46, 1029–1058.

Sarmiento, F.O., Frolich, L.M., 2002. Andean cloud forest tree lines: naturalness, agriculture and the human dimension. Mountain Research and Development 22, 278–287.

Soil Survey Staff, 1999. Soil Taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys. In: USDA Agriculture Handbook, 436. Washington DC.

Terrasi, F., De Cesare, N., D'onofrio, A., Lubritto, C., Marzaioli, F., Passariello, I., 2008. High precision ^{14}C AMS at CIRCE. Nuclear Instruments and Methods in Physics Research Section B 266, 2221–2224.

Terribile, F., Basile, A., De Mascellis, R., Iamarino, M., Magliulo, P., Pepe, S., 2007. Landslide processes and Andosols: the case study of the Campania region, Italy. In: Arnalds, O., Bartoli, F., Buurman, P., Oskarsson, H., Stoops, G., Garcıa-Rodeja, E. (Eds.), Soils of Volcanic Regions in Europe. Springer Verlag, Berlin and Heidelberg, pp. 545–563.

Thinon, M., 1978. La pédoanthracologie: une nouvelle méthode d'analyse phytochronologique depuis le néolithique. Comptes Rendues de l'Académie Des Sciences Paris, Série D 287, 1203–1206.

Tonneijck, F.H., Van der Plicht, J., Jansen, B., Verstraten, J.M., Hooghiemstra, H., 2006. Radiocarbon dating of soil organic matter fractions in Andosols in northern Ecuador. Radiocarbon 48, 337–353.

Tonneijck, F.H., Jos, A., Hageman, J.A., Jan Sevink, J., Verstraten, J.M., 2008. Tephra stratification of volcanic ash soils in Northern Ecuador. Geoderma 114, 231–247.

Touflan, P., Talon, B., 2009. Spatial reliability of soil charcoal analysis: the case of subalpine forest soils. Ecoscience 6, 23–27.

Van der Hammen, T., Hooghiemstra, H., 1995. The El Abra stadial: a Younger Dryas equivalent in Colombia. Quaternary Science Reviews 14, 841–851.

Van't Veer, R., Islebe, G.A., Hooghiemstra, H., 2000. Climatic change during the Younger Dryas chron in northern South America: a test of the evidence. Quaternary Science Reviews 19, 1821–1835.