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High spatial resolution of late-Holocene human activities in the moist forests of central Africa using soil charcoal and charred botanical remains

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Abstract

Palaeoecological and archaeological studies have demonstrated that human populations have long inhabited the moist forests of central Africa. However, spatial and temporal patterns of human activities have hardly been investigated with satisfactory accuracy. In this study, we propose to characterize past human activities at local scale by using a systematic quantitative and qualitative methodology based on soil charcoal and charred botanical remains. A total of 88 equidistant test-pits were excavated along six transects in two contrasting forest types in southern Cameroon. Charred botanical remains were collected by water-sieving and sorted by type (wood charcoals, oil palm endocarps and unidentified seeds). A total of 50 Accelerator Mass Spectrometry ^{14}C dates were also obtained. Results showed that charred macroremains were found at multiple places in the forest, suggesting scattered human activities, which were distributed into two main periods (Phase A: 2300–1300 BP; Phase B: 580 BP to the present). Charred botanical remains indicated two types of land-use: (1) domestic, with oil palm endocarps most often associated with potsherds (villages) and (2) agricultural, with charcoal as probable remnant of slash-and-burn cultivation (fields). Oil palm endocarp abundance decreased with distance from the identified human settlements. Our methodology allowed documenting, at high resolution, the spatial and temporal patterns of human activities in central African moist forests and could be applied to other tropical contexts.

Keywords

archaeology, charred endocarps, human settlements, late-Holocene, oil palm, soil charcoal, tropical Africa

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Introduction

Palaeoecological and archaeological evidence of ancient and scattered human activities have demonstrated that human populations have long inhabited the tropical forests worldwide (Barton et al., 2012; Willis et al., 2004). These biomes therefore cannot be regarded as pristine anymore, as they were occupied for several millennia by groups of hunter-gatherers, followed by farmers who settled in areas that are covered by dense forest today. In tropical Africa, it has been assumed that these human activities have had a substantial impact on vegetation structure and composition (Oslisly et al., 2013b). Specifically, early slash-and-burn shifting cultivation has been assumed to have formed scattered openings in the canopy that have allowed long-lived light-demanding trees to establish two to three centuries ago, and today, these trees represent an important component of canopy trees (Biwolé et al., 2015; Engone Obiang et al., 2014; Gond et al., 2013; Vleminckx et al., 2014). Nonetheless, this assumption raises three issues. The first relates to the distinction between anthropogenic and natural signals in the record, as natural fires have occurred irrespective of human presence, specifically during dry climatic events in the late-Holocene (i.e. after 2500 BP) (Hubau et al., 2015). The second issue concerns the observation scale, whether regional or local, of the anthropogenic disturbances and their impacts. The third deals with the quantitative and qualitative characterization of these human disturbances, especially in underexplored areas, because of difficulties related to fieldwork accessibility.

Numerous studies have documented an increasing human presence since the late-Holocene in tropical Africa (after 2500–2300

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BP; De Maret, 1986; Denbow, 1990; Eggert, 1992; Oslisly et al., 2013a; Wotzka, 2006), probably mediated by a strong dry climatic event that has been recorded between 3000 and 2000 BP throughout central Africa (Elenga et al., 1996; Lézine and McKey, 2013; Maley and Brenac, 1998; Ngomanda et al., 2009; Reynaud-Farrera et al., 1996; Vincens et al., 1999, 2010). Late-Holocene aridity resulted in a strong forest regression with patchy landscapes that may have contributed to the southwards expansion of Bantu-speaking populations, coming from the northwestern fringes of the Cameroonian forests (Clist, 2006; Lanfranchi et al., 1998; Schwartz, 1992; but see Eggert, 1992 for a review of the archaeo-linguistic aspects). Nonetheless, human history has hardly been documented precisely, particularly in the dense forests of southern Cameroon. Until now, only a few archaeological sites have been excavated (e.g. Eggert et al., 2006; Essomba, 1998; Lavachery et al., 2005; Meister, 2008, 2010; Neumann et al., 2012a). The systematic surveys undertaken during rescue excavations since the 2000s have constituted an exception in the almost empty archaeological landscape (e.g. the Campo Ma'an National Park and the Lolodorf–Kribi–Campo road-axe in SW Cameroon, the Lom Pangar dam and the Bertoua–Garoua–Boulaï road-axe in SE Cameroon (Mbida Mindzie et al., 2001; Oslisly, 2010). In contrast, archaeological findings in southern Cameroon have often depicted a rough image of scattered and localized human activities (Morin-Rivat et al., 2014). Indeed, they mainly consist of infrequent and incidental findings in the form of artefacts (e.g. stone tools, potsherds and iron slags) and charred botanical remains (e.g. charcoals and endocarps). Among the discoveries, wood charcoal is by far the most ubiquitous.

No agreed terminology or methods exist in charcoal studies, but rather a constellation of uses of charcoal to test various hypotheses in different biogeographical contexts (Scott and Damblon, 2010). In particular, pedoanthracology (i.e. the weighing, dating and identification of charcoals buried in soils; Carcaillet and Müller, 2005) has been developed then most often used in alpine and subalpine contexts (Carcaillet and Thinon, 1996; Thinon, 1978). Previous studies have dealt with treeline shifts and vegetation changes caused by Pleistocene natural paleofires, exacerbated by further late-Holocene anthropogenic burnings for agro-pastoral purposes (e.g. Carcaillet et al., 2009; Carnelli et al., 2004; Di Pasquale et al., 2008; Talon, 2010; Touflan et al., 2010). Charcoal has also been used to detect the spatial patterns of fire regimes as well as fire-return intervals in boreal and temperate forests (e.g. De Lafontaine and Payette, 2012; Gavin et al., 2003; Novák et al., 2012; Ohlson and Tryterud, 2000; Robin et al., 2011; Sanborn et al., 2006). In the Neotropics, charcoal analyses have demonstrated that climate was either the dominant driver of paleofires at some sites or that both climate and human activity were the main drivers during the mid-Holocene, whereas fires have been mainly attributed to man during the late-Holocene (McMichael et al., 2012; Tardy et al., 2000; Titiz and Sanford Jr, 2007). The Amazonian *Terra Preta* fertile soils constitute an emblematic example of dark earths from anthropogenic origin (Glaser, 2007; Glaser et al., 2000, 2001; Kämpf et al., 2003). These soils have been described as a mixture of slash-and-burn residues, waste and residential refuse, accumulated during extended occupation of archaeological sites. These remains have mainly been dated to the late-Holocene (Bush and Silman, 2007; Glaser et al., 2000; Hammond et al., 2006; Pessenda et al., 2004). In central Africa, charcoal analyses have mostly been limited to sedimentary micro charcoal from lakes or shallow depressions to detect ancient fire regimes at a regional scale (Aleman et al., 2013; Brncic et al., 2007, 2009; Tovar et al., 2014). Up until recent, studies on macro charcoal from soil have been scarce (Hart et al., 1996); however, they have been used lately in underexplored areas to link Quaternary fire events to past climate changes in the Democratic Republic of Congo (Hubau et al., 2012, 2013, 2015) and to test the relationship between anthropogenic disturbances and current vegetation in southern Cameroon (Biwolé et al., 2015; Bourland et al., 2015; Vleminckx et al., 2014). However, these recent studies have raised difficulties in the interpretation of the anthropogenic signal of disturbance. Issues namely arise related to either the sampling plan (Bourland et al., 2015) or to the quantitative methods, based on auger sampling (small sampled volumes) and charcoal hand-picking (Vleminckx et al., 2014). In addition, former soil charcoal samplings in the framework of archaeological research have highly been selective and have mainly considered points of interest in the landscape, such as ridges, watercourses or useful trees for local populations (Oslisly and White, 2003), but they have rarely been systematic. In any cases, a systematic and quantitative sampling, such as we propose in the present study, is crucial, especially for high-resolution analyses (Dutoit et al., 2009; Théry-Parisot et al., 2010).

In this study, we aimed at defining the spatial and temporal patterns of past human activities at local scale, by using a systematic quantitative and qualitative methodology based on dated indicators of human presence (i.e. artefacts) and land-use biomarkers (i.e. charcoal and other charred remains). In particular, we tested the presence, over time and at local scale, of different types of human activities, which has, to our knowledge, never been demonstrated with such accuracy in tropical Africa. We particularly tackled the following research questions: (1) Can a precise methodology, based on charred macrobotanical remains from soil pits, be used to detect human land-use (as opposed to natural change)? (2) Can this allow for a good interpretation of human activity and settlement in tropical Africa covered by dense forest? (3) What are the temporal patterns of this human activity? (4) What is its spatial extent over land?

Materials and methods

Study sites

The study was carried out between February and April 2012 in southern Cameroon (Figure 1), in two contrasting study sites in terms of vegetation, soil and geological substrate (hereafter called Site 1 and Site 2). The climate in both sites is equatorial, with two wet seasons interrupted by two dry seasons. The sites are located in forest management units (FMU) that are under FSC certificates for sustainable forest management. All forest concessions belong to the permanent forest domain and legislation prohibits agriculture in the concessions. Current villages and associated shifting cultivation are only located along the roads (Carrière, 1999 and personal observation). Current population density is less than 10 inhabitant/km^2 in Site 1 and less than 1 inhabitant/km^2 in Site 2 (Afripop, 2013).

Site 1 (2°10′–2°39′N, 10°11′–10°53′E) is located in south-western Cameroon, east of the Campo Ma'an National Park, in two FMU (logging company Wijma). Monthly average temperatures fluctuate around 25°C and mean annual rainfall ranges between 1669 (Bitam station, Gabon) and 2740 mm (Kribi station, http://www.climatedata.eu). The topography is hilly with a maximum altitude of 600 m. The geological substrate entails old volcanic intrusions and Precambrian metamorphic rocks (Franqueville, 1973), and is overlain by Ferralsols (red-dominant) and Acrisols (yellow-dominant) (Van Gemerden et al., 2003). The vegetation belongs to the mixed forest including lowland wet evergreen littoral and semi-deciduous types (Letouzey, 1985). The canopy is dominated by long-lived light-demanding species like *Lophira alata* (Ochnaceae) (Vleminckx et al., 2014).

Site 2 (2°30′–2°46′N, 10°42′–10°76′E) is located in southeastern Cameroon, north-east of the Dja Reserve, in three FMU (logging company SFID-Mbang, Groupe Rougier). Monthly average temperatures fluctuate around 28.5° and mean annual rainfall ranges between 1519 mm (Batouri station) and 1616 mm per year

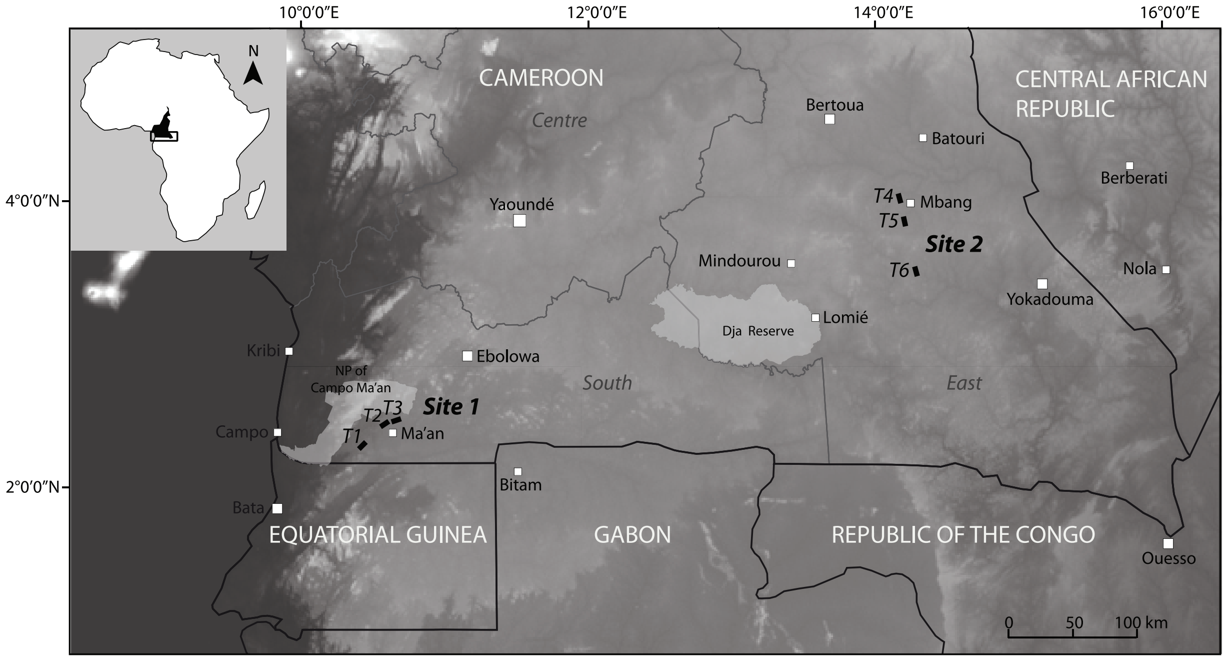

Figure 1. Location of the two study sites in southern Cameroon: Site 1 in the South Region near the Campo Ma'an National Park, Site 2 in the East Region near the Dja Reserve (park and reserve in light grey). The six study transects are indicated in black. SRTM base-map (http://srtm.csi.cgiar.org/).

(Lomié station, www.climatedata.eu). The topography is broadly flat, with altitude between 600 and 700 m. The geological substrate consists of weathered Precambrian schisto-quartzitic rocks (Vennetier, 1963), overlain by Ferralsols (Martin and Ségalen, 1966). The vegetation mainly belongs to the semi-deciduous forest types (Letouzey, 1985). Canopy is dominated by long-lived light-demanding species from the Cannabaceae (*Celtis* spp.) and Malvaceae (*Triplochiton scleroxylon*) families (Fayolle et al., 2014).

Sampling design

To document past human activities in the two study sites, we performed a systematic sampling along three transects in each study site that ran across all the FMU at each site (T1, T2 and T3 in Site 1; T4, T5 and T6 in Site 2) (Figure 1). We specifically chose unlogged areas in the forest concessions. In Site 1, transects were each 3 km long (9 km in total), the two most distant transects (T1 and T3) were 26 km apart. In Site 2, they reached 4.8 km (14.4 km in total). The two most distant (T4 and T6) were 63 km apart. Transects were shorter at Site 1 because of difficulties during fieldwork. At both sites, watercourses and swamps were located along transects. Along each transect, the slope was measured every 20 m with a clinometer to draw the topographic profiles. Sampling in riverbanks and swamps, including on steep slopes, was avoided because of inherent erosion and colluvium processes (in agreement with Carcaillet, 2001b). At each transect, a test-pit of 0.5 m × 0.5 m wide and 0.6 m deep was excavated every 250 m after removing the organic layer. We thus obtained a total of 12, 11 and 12 test-pits (P1 to P11/12) in T1, T2 and T3 of Site 1 and 19, 18 and 16 test-pits (P1 to P16/18/19) in T4, T5 and T6 of Site 2 which provided a total of 88 sampling test-pits for both sites (35 for Site 1 and 53 for Site 2). The skeletal content as well as the structure and colour of the soil were described (Carcaillet, 2001b), but no stratigraphic change was detected. Artefacts were extracted and inventoried by 10-cm layers. Reference pedological pits of 1 m × 1.3 m wide and 1.5 m deep were also excavated within each site (6 in Site 1 and 9 in Site 2) between 10- and 20-m distance from the test-pits. The reference soil profiles were oriented in a northwards direction. They were used for comparison purposes with the test-pits of the age–depth relationship.

Macrobotanical remains collection

To avoid human bias by hand-picking the visible charcoals and macroremains only (Carcaillet and Thinon, 1996), fixed volumes of 3 L of bulk soil were sampled by 10-cm layers, providing a total of 18 L of soil per test-pit. The soil samples were transported to the nearest watercourse and water-sieved directly on site through a 2-mm mesh sieve. The intermediate 2-mm mesh size constituted a good compromise between efforts during fieldwork, the sorting in laboratory and the possibility of further taxonomical identification on the macro charcoal fragments (i.e. ⩾1 mm according to the definition of Scott, 2010). Sieve refuses were subsequently air-dried.

In the laboratory, the charred botanical remains were manually separated from the mineral refusal under a dissection microscope (×20). To test whether the different categories of remains represent the same signals of human activity, we sorted them into three categories: (1) wood charcoals, (2) charred oil palm endocarps (*Elaeis guineensis*) and (3) unidentified charred seeds (in the absence of an exhaustive reference collection for these biomes). All materials were separately dried and subsequently weighted by depth and by category on a precision scale (0.01 g in accuracy).

Statistical analysis

For each study site, we tested Pearson correlation coefficients (using classical parametric test) between the quantities (g/L) of charcoal, oil palm endocarp and unidentified seeds (after performing a log (quantity + 1) transformation of these variables), in order to determine whether they characterized the same types of human activities. To test whether the different transects and test-pits experienced similar anthropogenic disturbance regimes, a linear mixed effect model with six factors (sites, depths, transects within sites, pits within transects, transects depending on depth within sites and pits depending on depth within sites) was performed on charcoal and oil palm endocarps separately (R software 3.2.4, www.r-project.org/). Sites, transects and test-pits were considered as random effects, while depth was defined as a fixed effect. The abundance of charcoal and oil palm endocarps underwent a logarithmic transformation to meet the assumption of normality (Biwolé et al., 2015).

Smaller scale spatial structures were characterized for each variable (within each site) by calculating their spatial autocorrelation using Moran's *I* statistic (Moran, 1948). The latter was computed as follows:

$$I_{ab} = \frac{\left(x_a - \bar{x}\right)\left(x_b - \bar{x}\right)}{Var\left(x\right)} + \frac{1}{\left(n-1\right)}$$

where x_1 and x_2 are, respectively, the values of variable X for samples a and b, while $\bar{x}$ and $Var(x)$ represent the mean and variance of the variable, respectively. The $1/(n-1)$ term was used to ensure that the average I_{ab} computed for all existing a, b pairs equals zero. Mean Moran's *I* values were computed for 12 to 14 distance intervals and plotted against spatial distance (autocorrelograms) to visually characterize spatial patterns at different scales: within a test-pit (distinguishing adjacent soil layers from layers separated by two to four layers), within a transect and among sites. Mantel tests between the spatial distance matrix and the I_{ab} matrix were performed to determine the significance of the spatial structure of each variable (Vleminckx et al., 2014).

Finally, we tested the Pearson correlation coefficient between each category of botanical remains and the distance to the nearest pottery discovery, in order to determine whether they were related to human settlement. To avoid type I error inflation due to spatial dependence between data points, correlation coefficients were tested by comparing the observed values with a null distribution of coefficients obtained after performing 4999 translations similar to torus-translations (Harms et al., 2001). More precisely, this procedure consisted in randomly shifting test-pits within each transect independently, while preserving the original disposition of the test-pits, except at transect extremities where test-pits were transposed to the opposite extremity (as if test-pits were located along a ring). *P*-values were then obtained as the proportion of correlation values lying outside the 95% confidence envelope. Spatial autocorrelation and torus-translation tests were performed using software Torocor 1.0 (http://ebe.ulb.ac.be/ebe/Software.html, Vleminckx et al., 2014). Input files for these analyses are available in the Supporting Information S1 and S2, available online.

Radiocarbon dating

Radiocarbon dating was performed on 50 charred pieces, namely 25 for each study site, including 37 on oil palm endocarps, 1 on an unidentified charred seed and 12 on wood charcoals in the absence of short-lived material (Table 1). Samples were chosen preferentially on hilltops or flat topographic situations to get reliable data from human sites (Oslisly and White, 2003) and to avoid colluvium (Carcaillet, 2001b). Two soil profiles up to 150-cm depth were chosen in T3 of Site 1 (plot P3) and T6 of Site 2 (plot P9) as reference profiles to test the age–depth relationship, with five oil palm endocarps dated at regularly spaced depths in each profile (by 20-cm layers in Site 1 and 10-cm layers in Site 2). All dates were obtained from samples with sizes ranging 2- to 4-mm diameter for charcoals, and up to 6-mm diameter for endocarps. Single oil palm endocarps or charcoals in direct contact with potsherds were used to estimate the age of pottery (Bourland et al., 2015). The Poznań Radiocarbon Laboratory (Poz) dated the 50 charcoal samples using Accelerator Mass Spectrometry (AMS). Calibration was performed in the OxCal v4.2.3 program (Bronk Ramsey, 2013) set with the IntCal13 atmospheric calibration curve (Reimer et al., 2013). To estimate the temporal distribution of events and to compare the two study sites, we performed a summed probability distribution of the radiocarbon dates calibrated in BP, in combination with a Bayesian model (Bronk Ramsey, 2009). Finally, we drew maps of the temporal patterns of each study site by using the same Bayesian distributions of the radiocarbon ages (Bronk Ramsey and Lee, 2013) and added the macroremains quantities for each dated plot (Supporting Information Figure S3, available online).

Results

Charcoal, oil palm endocarps and seeds spatial patterns

Macrobotanical remains were found in all transects (Figure 2). The summed masses ranged from 5.25 to 11.20 g/L in Site 1 (T3 and T1, respectively) and from 1.62 to 3.73 g/L in Site 2 (T5 and T6, respectively). The remains were present in 76 test-pits out of 88 (Site 1: all test-pits out of 35; in Site 2: 41 test-pits out of 53). They were found at all depths up to 60 cm in both sites. Charcoals were present in 71 test-pits out of 88 (Site 1: all test-pits out of 35; in Site 2: 36 test-pits out of 53) and represented 116.29 g in Site 1, 27.07 g in Site 2, while oil palm endocarps were present in 53 out of the 88 test-pits (Site 1: 32 test-pits out of 35; in Site 2: 36 test-pits out of 53) and represented 17.73 g in Site 1 and 24.91 g in Site 2. Unidentified seeds were less present as they were found in 34 test-pits out of 88 (Site 1: 14 test-pits out of 35; in Site 2: 20 test-pits out of 53). They represented 2.53 g in Site 1 and 1.41 g in Site 2.

Within each study site, no significant difference was observed for charcoal and oil palm endocarps abundance between transects (Table 2), while the abundance of unidentified seeds was significantly different between transects of Site 2 (namely more present in T4).

Significant spatial structures were found in both sites for charcoal and oil palm endocarps, while no significant Moran's *I* values were found for the seeds (Figure 3). However, spatial autocorrelation was only significant for soil layers separated by 10 to 25 cm for charcoal masses, and among all layers for oil palm endocarps.

Relationship between archaeological findings and the presence of charred botanical remains

Artefacts were found in 11 pits (5 pits in Site 1; 6 in Site 2), identifying the presence of human settlements in both study sites (Figure 2, Table 3). All potsherds were recorded on hilltops or plateaus and/or within 250–500 m of a watercourse. Two opaline–quartz flakes were also discovered in two soil profiles on transect T1 in the soil pit of plot 7 and on T3 in the soil pit of plot 3 between 70- and 80-cm depth. A grindstone in quarzitic sandstone and a quartz flake were found in Site 2 Transect 4 in a soil pit at 80, and two other flakes at 140-cm depth. Detailed analysis of the archaeological material will be performed in a future study.

The abundance of oil palm endocarps was significantly higher in test-pits where archaeological material was found (Table 4). However, no significant difference was observed regarding the abundances of charcoal and unidentified seeds. When plotting these abundances against the distance to the nearest pottery finding, we observed a decreasing trend that was more significant for oil palm endocarps than for charcoal or seeds in both sites (Figure 4). All trends were significant for oil palm endocarps but not for the two other macroremains categories, according to Pearson correlation tests. However, the only strong trend observed ($R^2 = 0.38$) declined ($R^2 \approx 0.06$) when removing the five plots separated by a null value. These five values were also far apart (great variation).

Radiocarbon ages temporal distribution

The 50 radiocarbon ages obtained spanned from 2800 cal. BP (Site 2) and 2350 cal. BP (Site 1) to the present time (Table 1, Figure 5), but with an older date around 10,700 cal. BP in Site 2 (Table 1). Ages were mainly distributed into two similar time

Table 1. The 50 radiocarbon AMS ages classified by site, transect, test-pit and pedological pits and depth. The reference soil profiles are indicated in bold.

Site	Transect	Test-pit	Depth (cm)	DM	Lab code	BP	±	Calibration		Archaeological phases	Associated archaeological findings
								68.2%	95.4%		
1	1	1	10–20	*OPE*	Poz-62641	1805	30	1810/1705	1822/1626	A	
1	1	4	10–20	*OPE*	Poz-62642	2250	30	2333/2181	2344/2155	A	
1	1	5	10–20	*OPE*	Poz-62644	2230	30	2316/2160	2333/2153	A	
1	1	7	20–40	*OPE*	Poz-49335	1540	30	1519/1386	1525/1363	A	
1	1	8	10–20	*OPE*	Poz-62645	780	30	726/681	741/669	B	
1	1	9	20–30	C	Poz-49330	145	30	275/9	283/2	B	Pottery
1	1	12	10–20	*OPE*	Poz-62646	1870	30	1868/1740	1877/1724	A	
1	2	1	10–20	*OPE*	Poz-62647	1810	30	1810/1709	1823/1628	B	
1	2	3	10–20	*OPE*	Poz-62648	1960	30	1945/1877	1989/1830	A	
1	2	4	0–20	*OPE*	Poz-49334	150	25	277/8	284/0	B	
1	2	5	10–20	*OPE*	Poz-62649	1655	30	1599/1530	1688/1420	A	
1	2	6	10–20	*OPE*	Poz-62650	1705	30	1690/1561	1698/1549	A	
1	2	8	0–10	*OPE*	Poz-62651	1860	30	1861/1737	1870/1720	A	
1	2	10	30–40	*OPE*	Poz-49331	1750	35	1707/1616	1775/1560	A	
1	3	2	20–30	*OPE*	Poz-62653	1865	30	1864/1739	1874/1720	A	
1	3	3	10–20	*OPE*	Poz-62654	1660	30	1602/1533	1690/1421	A	
1	**3**	**3**	**0–10**	**C**	**Poz-49323**	**260**	**30**	**421/156**	**431/0**	**B**	**Pottery**
1	**3**	**3**	**30–40**	***OPE***	**Poz-49324**	**1810**	**30**	**1810/1709**	**1823/1628**	**A**	**Pottery**
1	**3**	**3**	**70–80**	***OPE***	**Poz-49327**	**2160**	**30**	**2301/2116**	**2307/2057**	**A**	
1	**3**	**3**	**100–110**	***OPE***	**Poz-49328**	**2005**	**30**	**1991/1926**	**2038/1883**	**A**	
1	**3**	**3**	**140–150**	***OPE***	**Poz-49329**	**2090**	**30**	**2112/2005**	**2144/1991**	**A**	
1	3	8	20–30	*OPE*	Poz-62655	1495	30	1405/1347	1516/1310	A	
1	3	9	20–30	*OPE*	Poz-62656	625	30	653/559	661/551	B	
1	3	9	30–40	*OPE*	Poz-49333	1790	30	1805/1628	1817/1620	A	
1	3	11	0–10	*OPE*	Poz-62657	1720	30	1693/1569	1703/1560	A	
2	4	2	10–20	*OPE*	Poz-62626	1810	30	1810/1709	1823/1628	A	Pottery
2	4	2	50–60	*OPE*	Poz-62625	1750	30	1705/1619	1729/1565	A	Pottery
2	4	4	10–20	*OPE*	Poz-62627	860	30	791/732	901/695	B	
2	4	10	10–20	C	Poz-62628	2090	30	2112/2005	2144/1991	A	
2	4	13	10–20	C	Poz-62629	175	35	285/0	298/0	B	
2	4	14	0–10	CE	Poz-49337	1825	35	1813/1720	1865/1630	A	
2	4	14	30–40	C	Poz-49338	2220	30	2310/2159	2324/2152	A	
2	5	1	10–20	C	Poz-62630	305	30	429/306	462/300	B	
2	5	4	20–30	C	Poz-62631	1610	35	1552/1417	1568/1407	A	
2	5	7	30–40	*OPE*	Poz-62632	2265	30	2342/2185	2348/2158	A	
2	5	8	20–30	C	Poz-49339	1915	30	1888/1825	1935/1742	A	
2	5	9	0–10	C	Poz-49340	2745	30	2861/2791	2923/2768	A	
2	5	9	30–40	*OPE*	Poz-49341	1670	35	1610/1538	1695/1423	A	
2	5	13	20–30	*OPE*	Poz-62634	360	30	484/325	500/315	B	
2	6	3	20–30	*OPE*	Poz-62635	1775	30	1727/1622	1813/1611	A	
2	6	7	10–20	*OPE*	Poz-62636	2195	30	2305/2150	2312/2132	A	
2	**6**	**9**	**0–10**	***OPE***	**Poz-49342**	**2190**	**30**	**2305/2148**	**2310/2127**	**A**	
2	**6**	**9**	**30–40**	***OPE***	**Poz-49343**	**2165**	**30**	**2301/2120**	**2308/2061**	**A**	
2	**6**	**9**	**70–80**	***OPE***	**Poz-49344**	**2250**	**35**	**2335/2180**	**2345/2155**	**A**	
2	**6**	**9**	**100–110**	***OPE***	**Poz-49325**	**9400**	**50**	**10,692/10,575**	**10,748/10,507**		
2	**6**	**9**	**140–150**	***OPE***	**Poz-49345**	**2275**	**30**	**2346/2206**	**2350/2159**	**A**	
2	6	12	10–20	C	Poz-62637	140	30	271/11	281/6	B	
2	6	13	20–30	C	Poz-62638	260	30	421/156	431/0	B	
2	6	15	10–20	*OPE*	Poz-62639	1745	30	1700/1618	1720/1565	A	
2	6	16	10–20	C	Poz-62640	80	30	254/33	260/25	B	

DM: dated material; C: Charcoal; CE: Charred endocarp (unidentified taxon); *OPE*: oil palm endocarp *Elaeis guineensis*; A and B: identified archaeological Phase A and Phase B; AMS: Accelerator Mass Spectrometry; BP: Before Present.

periods, with slight time shifts between the study sites: (1) a first period between 2350 and 1500/1350 cal. BP (Phase A), (2) a second period, with fewer dates between 1500/1350 and 580/300 cal. BP (hiatus) and (3) a third period between 580/300 cal. BP and the present (Phase B).

The age–depth relationship was weak at both sites (see Vleminckx et al., 2014), but with similar patterns. Young dates after 800 cal. BP concentrated in the first 30-cm depth while older dates between 1500 and 2800 cal. BP clustered in the first 40-cm depth. Radiocarbon ages focused on 2300 cal. BP were found deeper than 40 cm (i.e. in the reference soil pits at both sites). The oldest date around 10,700 cal. BP in Site 2 was found between 100 and 110 cm.

Modelled distributions of the radiocarbon ages were mapped at 200-year intervals (Supporting Information Figure S3a for Site 1;

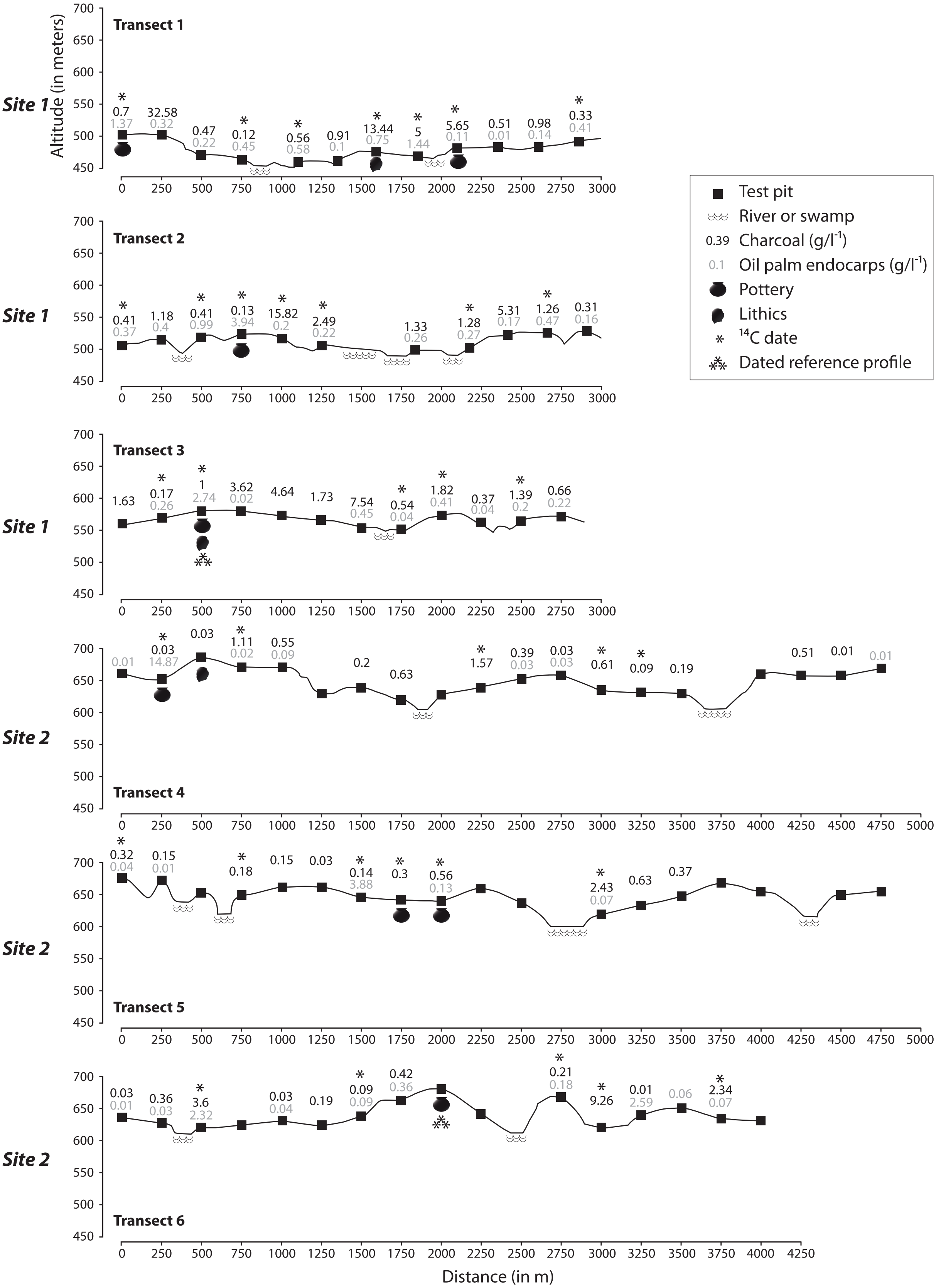

Figure 2. The six transects and the 88 test-pits investigated. The total masses (in grams) of charcoal (in black) and oil palm endocarps (in grey) by test-pit as well as the archaeological findings are reported. Null values and masses of unidentified seeds are not represented.

S3b for Site 2, available online). The distributions showed the discontinuity of spatial occupation over time and the 2000- to 2800-km spacing between synchronous human activities in a same transect, especially around 1800 BP in both sites. Distances dropped below 2000 km around 1600 BP. The maps also demonstrated a southward displacement of the disturbances over time in Site 2. Charcoal and oil palm endocarps quantities in the dated test-pits showed reverse trends between very spatially close test-pits in the same transect. In addition, potsherds were more often associated with larger quantities of oil palm endocarps.

Table 2. Summary of linear mixed effect model with six factors (sites, depths, transects within sites, test-pits within transects, transects depending on depth, test-pits depending on depth) performed on the abundances (grams per litre) of charcoal and oil palm endocarps. Sites, transects and test-pits were considered as random effects, while soil depth was defined as a fixed effect. Significant differences are highlighted in bold.

Variables	Effect	DF	Charcoal		Oil palm endocarps	
			F	*p*	*F*	*p*
Site	Random	1	**27.99**	**0.004**	5.34	0.067
Depth	Fixed	5	2.17	0.102	1.92	0.140
Transect (Site)	Random	4	0.69	0.604	0.31	0.867
Pits (Site Transect)	Random	82	**4.24**	**0.000**	**3.67**	**0.000**
Transect*Depth (Site)	Fixed	20	1.10	0.345	0.96	0.507
Pits*Depth (Site Transect)	Fixed	410	0.38	0.976	2.25	0.182

DF: degree of freedom; *F*: The *F*-statistic value; *p*: probability value.

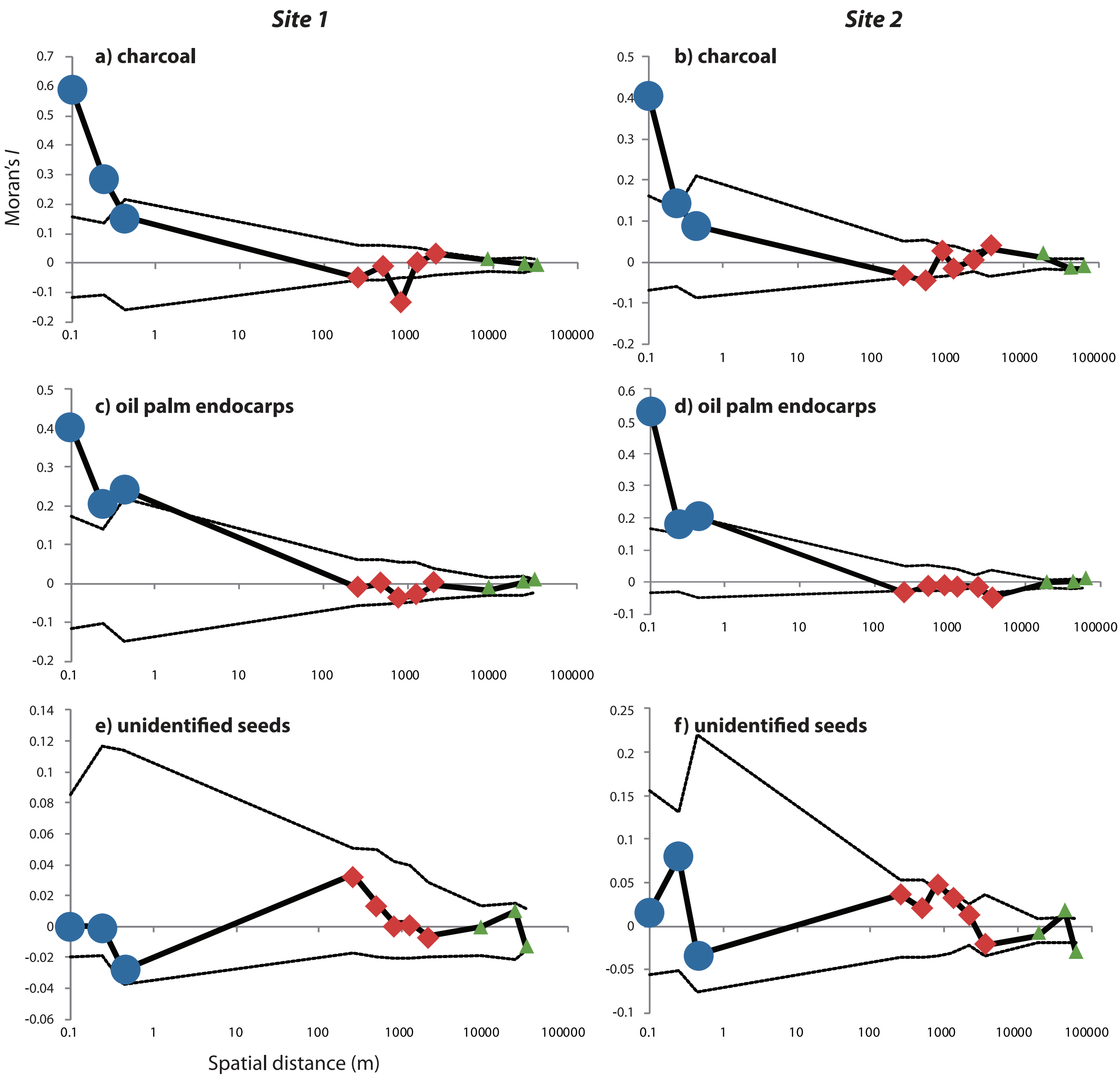

Figure 3. Autocorrelograms of charcoal abundance values for each study area: mean Moran's *I* computed for 12 to 14 distance intervals. On the left side (<1 m), the abscissa for the three first symbols (big blue discs) represent the vertical distance between soil layers from a single test-pit, the first symbol distinguishing adjacent layers, while the second and third symbols distinguish non-adjacent layers separated by 25 and 45 cm, respectively. On the right side (>10 m), the abscissa corresponds to horizontal distance between soil volumes from different test-pits located in different plots from a same transect (between 100 and 5000 m, red lozenges), and from different plots from different transects (>5000 m, green triangles). Symbols above or below the dashed lines indicate significantly positive or negative Moran's *I* value ($p < 0.05$).

Table 3. Pottery findings in eight pits from Sites 1 and 2. Fragment number is indicated by depth.

	Transect	Plot	Soil profile	Depth (cm)							
				0–10	10–20	20–30	30–40	40–50	50–60	60–70	Total no.
Site 1	1	1					3	1			4
	1	9		36	32	7			1		76
	2	4	x	18	21	4	3				46
	3	3	x	7	7	1		4	3	1	23
Site 2	4	2			6	12	11	7	35	7	78
	5	8			7						7
	5	8	x			19	15	18	2		54
	5	9			2	4					6

Table 4. Mass (g/L) of charcoal, oil palm endocarps (OPE) and unidentified seeds (Un. seeds) in test-pits where an absence or presence of pottery was recorded. *P*-values (Wilcoxon test) indicate the significance of the difference between the two cases.

	Absence of pottery	Presence of pottery	*p*-value (Wilcoxon test)
Charcoal	0.34 (±*0.07*)	0.55 (±*0.28*)	0.39
OPE	0.08 (±*0.02*)	0.55 (±*0.25*)	**0.03***
Un. seeds	0.02 (±*5.61 10^{-3}*)	8.29 10^{-3} (±*3.83 10^{-3}*)	0.77

*Significant at 0.05.

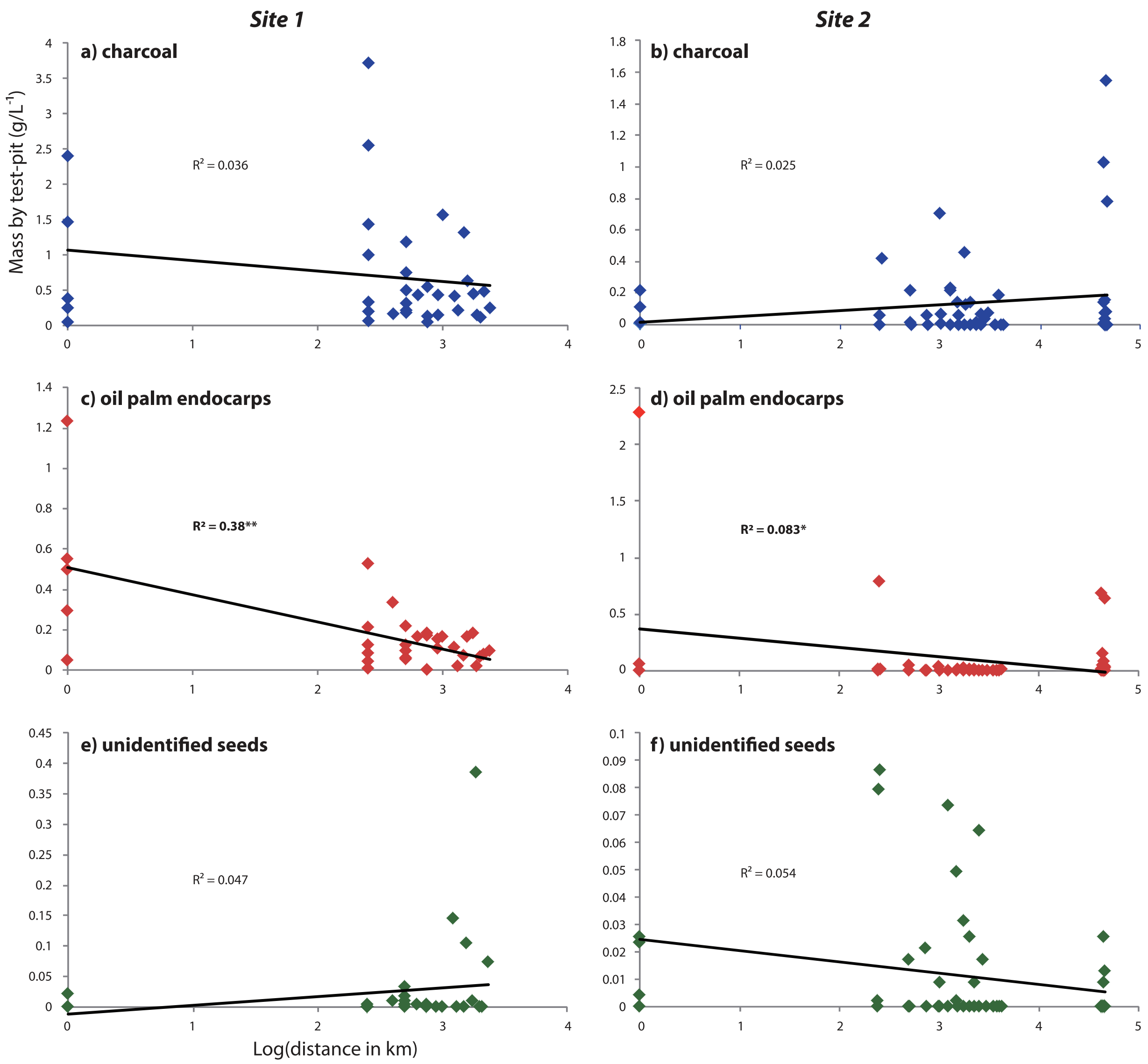

Figure 4. Relationship between (1) the abundance of charcoal, oil palm endocarps and unidentified seeds, and (2) the distance to the nearest pottery findings. Correlation values between the distance to (1) the nearest pottery findings and (2) the abundance of charcoal, oil palm endocarps and unidentified seeds, and their significance according to the torus-translation procedure are indicated on each graph.

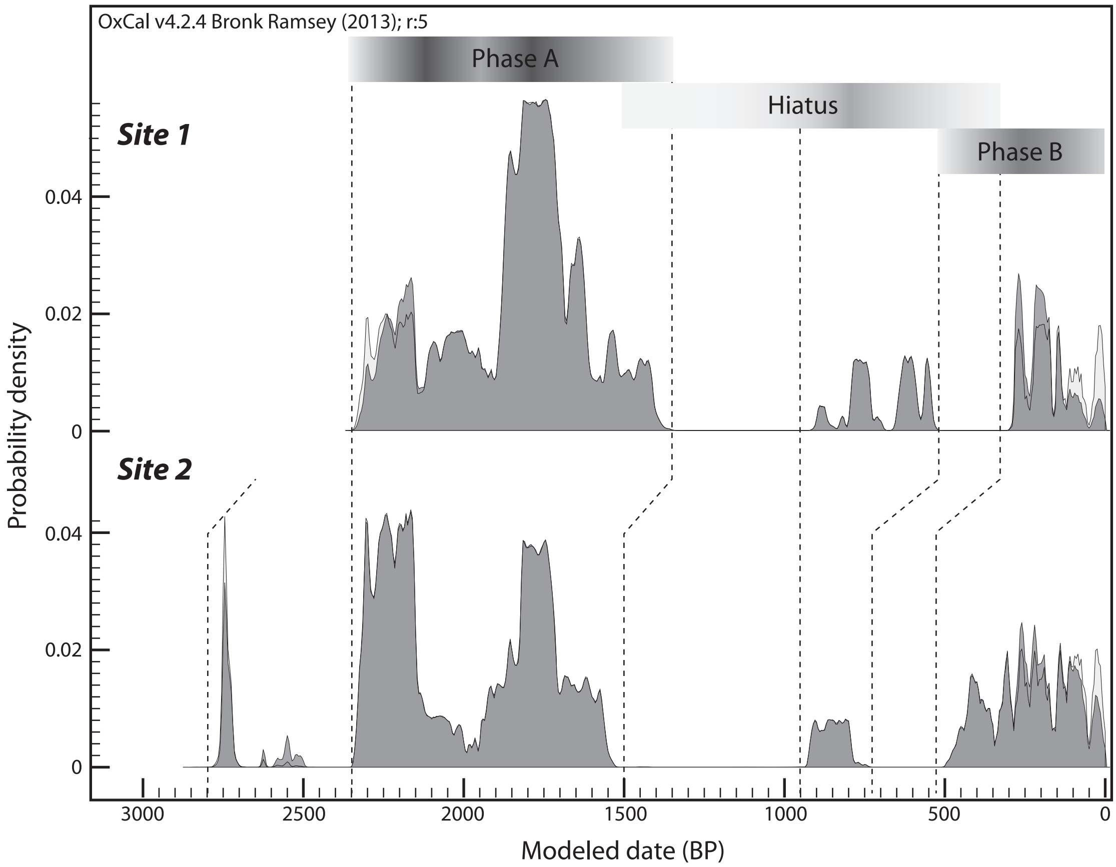

Figure 5. Modelled probability density (dark grey) of the 49 radiocarbon dates between 2800 to the present in cal. BP (the oldest date at 10,700 cal. BP is not shown). Light grey indicates the probability removed from the model. Black dashed lines between the peaks of the curves represented temporal differences between Sites 1 and 2. Three periods were delimited: (1) a Phase A (2300–1500/1350 cal. BP), (2) a hiatus phase with less occupation (1500/1350–580/300 cal. BP) and (3) a Phase B (580/300 cal. BP to the present).

Discussion

In this study, we aimed at characterizing the temporal and spatial patterns of human activity at local scale in the dense forests of southern Cameroon by using a systematic sampling protocol. The majority of charred macrobotanical remains were considered as by-products of human land-use in our study (sensu Glaser, 2007). We found evidence of scattered human settlements and activity in the two study sites, which were mainly dated to the late-Holocene (after 2500 BP). Archaeological remains, in the form of artefacts and biomarkers (i.e. charcoals and charred seeds), showed different spatial patterns according to their location along the study transects, revealing two main types of human activities: domestic and agricultural. These results support the relevance of an analysis based on soil charred macrobotanical remains to test spatial patterns of past human land-use in tropical contexts.

Human-induced paleofires

The discrimination between natural and anthropogenic fires since the Holocene remains a complex issue in the absence of archaeological evidence, such as potsherds (Conedera et al., 2009; Scott and Damblon, 2010; Théry-Parisot et al., 2010), and more specifically in underexplored regions (Di Pasquale et al., 2008; Hubau et al., 2014, 2015). However, three arguments could allow for the interpretation of charred biomarkers as human-induced in our study sites: (1) their local significance, (2) their scattered distribution both in time and space, and (3) a reduced probability of natural fires during the period considered.

Paleofires were local. To detect the local nature of human activities, we analysed charred botanical remains of ⩾2 mm. Previous studies on paleofires and experimental work have shown, indeed, that macro charcoals of ⩾0.4 mm, and most often of ⩾2 mm, dominated the charcoal records (94% of the mass in Ohlson and Tryterud, 2000) and provided information about local fires due to limited transport of this fragment size (Clark, 1988; Clark and Patterson, 1997; Conedera et al., 2009; Eckmeier et al., 2007; Ohlson and Tryterud, 2000; Scott and Damblon, 2010). At maximum, charred macroremains derived from within a few hundred metres of the source area of their production (Conedera et al., 2009). Furthermore, the admixture of macro charcoals and macrobotanical remains of different sizes and shapes in our records confirms *in situ* assemblages resulting from local fires (Conedera et al., 2009; Scott, 2010). Finally, Hubau et al. (2015) demonstrated that test-pits recorded one burning only or that charcoals were stratified in separate layers. Moreover, when there was only one burning per pit, the same few species have been identified throughout the profile. Charcoal identification is still in progress in our study sites, but preliminary results show the same trends. We can thus be rather confident that macroremains actually captured discreet and very local fire events, despite their vertical dispersion.

Paleofires were scattered. Regarding their distribution, charcoal and charred botanical remains were unearthed everywhere at both sites, with no specific spatial structure, with the exception of the unidentified seeds which were found in greater quantity in transect T4 of Site 2. Spatial structures were only significant for charcoals and oil palm endocarps coming from the same test-pits. This suggests that charred remains were scattered and that there was no relationship between fire events detected in two adjacent or non-adjacent test-pits. This can correspond to a much-localized response of charcoal and oil palm endocarp abundance by depth that also strongly varied between test-pits. Inter-pit variability relative to charcoal concentration has already been demonstrated at local scale (Touflan and Talon, 2009). This variability could be linked to biomass differences at the time of burning, which we cannot estimate in the current state of knowledge, because of uncertainties related to biomass estimations for tropical African forests (see, for example, Kearsley et al., 2013). Nonetheless, Brando et al. (2016) recently demonstrated in neotropical forests that fires little affected large trees >30 cm in diameter at breast height (dbh). The fact that we found the same temporal and spatial patterns of scattered fires in our two study sites, corresponding to two contrasting situations in terms of environmental conditions and vegetation, confirms the discontinuity of late-Holocene paleofires. Moreover, the absence of synchronicity of the fires and the local origin of soil charcoals (Carcaillet et al., 2009; Conedera et al., 2009; Whitlock and Larsen, 2001) compared with sedimentary charcoals close to our study sites (e.g. the Ntem Interior for Site 1, and Goualougo Lake and Mopo Baï in the Republic of the Congo for Site 2, Brncic et al., 2007, 2009; Tovar et al., 2014) also supports the assumption of scattered fires in southern Cameroon as being a general trend.

Paleofires were rarely natural. The only old age, obtained at Site 2 (Poz-49325, 9400 BP), corresponds to the late-Pleistocene/Holocene transition (Sangen, 2012; Sangen et al., 2010). A climate with reduced precipitation has caused the shrinkage of the central African moist forests of the order of 84% (Anhuf et al., 2006). Those drier climatic conditions may have favoured the ignition of natural fires at that time (Hubau et al., 2013, 2015) in the absence of a dense prehistoric and impacting population (Cornelissen, 2002). The main body of radiocarbon ages indicates that paleofires concentrated during the late-Holocene (after 2500 BP). This occurred after the First Millennium Rainforest Crisis (Ngomanda et al., 2009), a strong dry event around 2500 BP in central Africa that has induced forest fragmentation and could have driven agriculturists to expand southwards in the forest (Clist, 2006; Lanfranchi et al., 1998; Schwartz, 1992). Climate was less dry after this time, reducing the probability of natural fires to occur (Bostoen et al., 2013; Brncic et al., 2009; Lézine et al., 2013; Maley et al., 2012). Indeed, even increased fuel loads in the understory were unlikely to create catastrophic fires outside periods of intense drought (Brando et al., 2016). But, after 2500 BP, alluvial sediments in the surroundings of both study sites (the Ntem Interior delta, the upper Nyong, Sanaga, Boumba, Dja and Ngoko valleys, Runge et al., 2014; Sangen, 2012; Sangen et al., 2010) have recorded an increased erosion coinciding with forest regression (Neumer et al., 2008), coupled with a growing number of archaeological sites and discoveries in southern Cameroon (Bourland et al., 2015; Höhn et al., 2008; Meister, 2008; Morin-Rivat et al., 2014; Oslisly et al., 2013a, 2013b; Sangen, 2012; Wotzka, 2006). We also found much more charcoal in Site 1 than in Site 2, despite the fact that Site 1 receives more rainfall and is thus more humid, supporting the hypothesis of important anthropogenic disturbances in the area. The great amounts of charcoal and macrobotanical remains trapped in the riverbanks have also been interpreted as remnants of slash-and-burn agriculture (Sangen, 2012). We do not exclude, however, the possibility of small-scale natural paleofires in periods of severe droughts in relation with ENSO events (Hammond et al., 2006; Hubau et al., 2015; Neumann et al., 2012a, 2012b; Scott, 2000; Titiz and Sanford Jr, 2007).

Ancient land-use in southern Cameroon

Late-Holocene human occupations. The set of 49 radiocarbon ages, excluding one date (Poz-49325, 9400 BP), clearly concentrates to the late-Holocene (after 2500 BP), in agreement with previous works (Oslisly et al., 2013a, 2013b; Wotzka, 2006) that have reported an increase in the number of archaeological sites during this period. Moreover, despite the fact that the two study sites were 350 km apart, the ages were distributed according to the two same well-known archaeological periods: (1) 2300–1500 (Site 2)/1300 (Site 1) BP, and (2) 580 (Site 2)/300 (Site 1) BP to the present. We suggest to use Phases A and B, instead of the too largely used early and late Iron Age (Phillipson, 2005), because we cannot be sure of the identity of past populations in our study areas. Pyro-technologies were represented by pottery in both sites and iron metallurgy in the study areas (Eggert et al., 2006; Morin-Rivat et al., 2014), which suggest scattered human settlements. The bimodal pattern of human occupation, characterized by an intermediate hiatus in the radiocarbon ages between 1500 (Site 2)/1300 (Site 1) and 580 (Site 2)/300 (Site 1) BP, has already been reported for central Africa (Oslisly et al., 2013a, 2013b; Wotzka, 2006) and for southern Cameroon in particular (Morin-Rivat et al., 2014). This hiatus phase has been interpreted as a population collapse (Oslisly, 2001; Schwartz, 1992). Its definitive explanation is still debated (Wotzka, 2006), with propositions related to widespread epidemic diseases (e.g. trypanosomiasis) and famines (Oslisly, 2001; Oslisly et al., 2013a) or destructive taphonomic processes of the human settlements (Wotzka, 2006). We suggest, however, that the slave trade since the 15th century could partly have an impact on human populations by raiding peoples far into the forest. Especially, the time shift between Site 1 and Site 2 at the end of this hiatus (580/300 BP) could be explained by populations displacements eastwards.

Past human activities and land-use management. The absence of correlation between charcoal and oil palm endocarps supports the hypothesis that they did not represent the same types of events and probably of human activities. Moreover, there was a relationship between potsherds and oil palm endocarps, the latter most often associated with potsherds than with charcoal only, and found in higher positions, such as hilltops in the vicinity of watercourses. Rivers are usually considered as aggregation sites for populations in tropical environments (Bush and Silman, 2007; McMichael et al., 2012; Oslisly and White, 2003). This combination between potsherds and oil palm endocarps thus seems to represent domestic activities in human settlements, as reported in several sites in southern Cameroon (Eggert et al., 2006). By contrast, charcoal and unidentified seeds followed other trends and were less often associated with pottery findings. We suppose that they can represent other signals, more distant to human settlements. Seeds were not numerous but showed various patterns of abundance. Their presence may be interpreted as the burning of wild plant species, either during wild fires or slash-and-burn agricultural activities. In general, charcoal presence may correspond to agricultural practices and to slash-and-burn shifting cultivation in particular, notwithstanding specific domestic contexts (e.g. domestic hearths). We also found that synchronous human activities around 1800 BP could be spaced between 2000 and 2800 m apart. This may correspond to the land needed for a village to thrive. Two centuries later, around 1600 BP, this distance dropped below 2000 m (i.e. 1750 m in average). This may be linked to a peak in human occupation during Phase A (Oslisly et al., 2013a, 2013b; Wotzka, 2006), which may suggest a peak in human density in both study areas. Distance between contemporaneous activities may thus be reduced with increasing population. People currently walk 2-km distance to go cultivate their fields in southern Cameroon (Carrière, 2002). However, we cannot transfer the present situation to the past, even though a traditional land-use as described in southern Cameroon is likely, with shifting fields located in the village lands (Vermeulen and Karsenty, 2001). It can be assumed that people moved their villages because of soil exhaustion over generations, or for political purposes, such as alliances (e.g. same family, ethnic group), conflict management (Vermeulen and Karsenty, 2001) or because of disease outbreaks (e.g. ebola). All these elements suggest that people may have been a crucial factor in the presence of charcoal. We assumed that these populations, even two millennia ago and up to the 19th century, had a deep knowledge of their long-term land-use and their spatial occupation.

Charcoal for slash-and-burn cultivation. Iron smelting and shifting agriculture yielded large quantities of charcoal (Neumann et al., 2012a; Oslisly et al., 2013b). In our study sites, no metallurgical slags or '*tuyères*' fragments have been discovered so far, which makes the assumption of charcoals as remnants of agricultural practices more likely. Agriculture has been rarely demonstrated in Africa's dense forest in the absence of obvious evidence, for instance pearl millet seeds (*Pennisetum glaucum*), as discovered in southern Cameroon and dated to 2200 BP (Eggert et al., 2006; Kahlheber et al., 2009; Neumann et al., 2012a). The use of late-Holocene soil charcoals is thus of great interest to track past agricultural practices within the African moist forest (Morin-Rivat et al., 2014). In our study, oil palm endocarps add another interesting element of discussion relative to the utilization of wild plant resources by past populations (Clist, 1997; Lavachery, 2001; Lavachery et al., 2005; Logan and D'Andrea, 2012). Recently, similar discoveries from the northern Congo Basin (Morin-Rivat et al., 2014) have been classified by Kay and Kaplan (2015) as originating from 'foragers-horticulturists' rather than from true agriculturists.

Conclusion

This study has demonstrated the statistical power of using charcoal and charred botanical remains so as to interpret past land-use in tropical contexts. Nonetheless, this does not exclude some limitations. The first one relies on the linear sampling used in this study, which could not afford exhaustive information on human activities, but brought information along great distances. An improvement of this could be a sampling according to a grid. Second, this method needs large soil quantities to collect the charred botanical remains (see Di Pasquale et al., 2008), which could potentially give a lower temporal resolution than in sedimentary charcoals from lakes (Whitlock and Larsen, 2001). Even though we reduced the thickness of the soil layers (10 cm versus 25 cm in Di Pasquale et al., 2008) to try to increase the temporal resolution of our records, only weak age–depth relationships emerged, especially in Site 2. Nonetheless, the most recent dates came generally from the topmost 40 cm of the test-pits with increasing age with depth (Hubau et al., 2015; Vleminckx et al., 2014), which is also consistent with previous results on tropical soils (Hammond et al., 2006; Vleminckx et al., 2014). Additional geomorphological and pedological work should be done, however, in order to understand soil formation, accumulation rate and disturbance processes in African tropical soils. Indeed, we cannot exclude likely post-depositional processes in our study sites, such as soil reworking by soil fauna, uprooting, erosion, burrowing and decomposition (Conedera et al., 2009; Théry-Parisot et al., 2010). Finally, attention should be paid to the potential inbuilt ages of the dated charcoal compared with the short-lived endocarps, as they could come from long-lived trees and could thus overestimate the actual ages by several hundreds of years (Gavin, 2001; Hammond et al., 2006).

In spite of these limitations, it does not understate the interest of the method in terms of spatial study of past disturbances (Carcaillet, 2001a, 2001b), and clear advantages emerged from an approach based on different categories of land-use biomarkers (Conedera et al., 2009; Di Pasquale et al., 2008; Ohlson and Tryterud, 2000; Robin et al., 2013). The repetition of our sampling in two different study sites that represented contrasting ecological situations, the large number of replicates in terms of test-pits (88) and soil samples (528), as well as the 50 radiocarbon ages obtained, contribute to the reliability of our results (Conedera et al., 2009; Eckmeier et al., 2007; Gavin et al., 2003; Touflan and Talon, 2009). The ubiquity of charcoal and its good preservation in soils over the limited number of suitable sites for palynology and sedimentary charcoal (Robin et al., 2013) make it a highly relevant tool, especially to discover human settlements and activities in areas that have not been archaeologically surveyed. Our results also highlighted agricultural practices that have long been neglected and thus open the way for a very practical archaeology of land-use and landscapes in tropical contexts.

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References

Afripop (2013) Afripop project. Available at: http://www.worldpop.org.uk/data/summary/?contselect=Africa&countselect=Cameroon&typeselect=Population.

Aleman JC, Blarquez O, Bentaleb I et al. (2013) Tracking land-cover changes with sedimentary charcoal in the Afrotropics. *The Holocene* 23(12): 1853–1862.

Anhuf D, Ledru MP, Behling H et al. (2006) Paleo-environmental change in Amazonian and African rainforest during the LGM. *Palaeogeography, Palaeoclimatology, Palaeoecology* 239(3): 510–527.

Barton H, Denham T, Neumann K et al. (2012) Guest editorial – Long-term perspectives on human occupation of tropical rainforests: An introductory overview. *Quaternary International* 249: 1–3.

Biwolé AB, Morin-Rivat J, Fayolle A et al. (2015) New data on the recent history of the littoral forests of southern Cameroon: An insight into the role of historical human disturbances on the current forest composition. *Plant Ecology and Evolution* 148(1): 19–28.

Bostoen K, Grollemund R and Muluwa JK (2013) Climate-induced vegetation dynamics and the Bantu Expansion: Evidence from Bantu names for pioneer trees (Elaeis guineensis, Canarium schweinfurthii, and Musanga cecropioides). *Comptes Rendus Geoscience* 345: 336–349.

Bourland N, Cerisier F, Daïnou K et al. (2015) How tightly linked are *Pericopsis elata* (Fabaceae) patches to anthropogenic disturbances in Southeastern Cameroon? *Forests* 6(2): 293–310.

Brando PM, Oliveria-Santos C, Rocha W et al. (2016) Effects of experimental fuel additions on fire intensity and severity: Unexpected carbon resilience of a neotropical forest. *Global Change Biology*. Epub ahead of print 10 January. DOI: 10.1111/gcb.13172.

Brncic TM, Willis MKJ, Harris DJ et al. (2007) Culture or climate? The relative influences of past processes on the composition of the lowland Congo rainforest. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 362: 229–242.

Brncic TM, Willis MKJ, Harris DJ et al. (2009) Fire and climate change impacts on lowland forest composition in northern Congo during the last 2580 years from palaeoecological analyses of a seasonally flooded swamp. *The Holocene* 19(1): 79–89.

Bronk Ramsey C (2009) Bayesian analysis of radiocarbon dates. *Radiocarbon* 51(1): 337–360.

Bronk Ramsey C (2013) OxCal 4.2 manual. Available at: https://c14.arch.ox.ac.uk/OxCal.html.

Bronk Ramsey C and Lee S (2013) Recent and planned developments of the program OxCal. *Radiocarbon* 55(2–3): 720–730.

Bush MB and Silman MR (2007) Amazonian exploitation revisited: Ecological asymmetry and the policy pendulum. *Frontiers in Ecology and the Environment* 5(9): 457–465.

Carcaillet C (2001a) Are Holocene wood-charcoal fragments stratified in alpine and subalpine soils? Evidence from the Alps based on AMS ^{14}C dates. *The Holocene* 11(2): 231–242.

Carcaillet C (2001b) Soil particles reworking evidences by AMS 14C dating of charcoal. *Comptes Rendus de l'Académie des Sciences, Series IIA: Earth and Planetary Science* 332: 21–28.

Carcaillet C and Müller SD (2005) Holocene tree-limit and distribution of *Abies alba* in the inner French Alps: Anthropogenic or climatic changes? *Boreas* 34: 468–476.

Carcaillet C and Thinon M (1996) Pedoanthracological contribution to the study of 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.

Carcaillet C, Ali AA, Blarquez O et al. (2009) Spatial variability of fire history in subalpine forests: From natural to cultural regimes. *Écoscience* 16(1): 1–12.

Carnelli AL, Theurillat J-P, Thinon M et al. (2004) Past uppermost tree limit in the Central European Alps (Switzerland) based on soil and soil charcoal. *The Holocene* 14(3): 393–405.

Carrière S (1999) *Les orphelins de la forêt. Influence de l'agriculture itinérante sur brûlis des Ntumu et des pratiques agricoles associées sur la dynamique forestière du sud Cameroun*. PhD Thesis, Université de Montpellier II.

Carrière S (2002) 'Orphan trees of the forest': Why do Ntumu farmers of southern Cameroon protect trees in their swidden fields? *Journal of Ethnobiology* 22(1): 133–162.

Clark JS (1988) Particle motion and the theory of charcoal analysis: Source area, transport, deposition, and sampling. *Quaternary Research* 30: 81–91.

Clark JS and Patterson WA, III (1997) Background and local charcoal in sediments: Scales of fire evidence in the palaeo record. In: Clark JS, Cachier H, Goldammer JG et al. (eds) *Sediment Records of Biomass Burning and Global Change*. Berlin: Springer-Verlag, pp. 23–48.

Clist B (1997) Le site d'Okala, Province de I'Estuaire, Gabon, et son importance pour la compréhension du passage à la sédentarisation en Afrique centrale. *Comptes Rendus de l'Académie des Sciences, série IIA: Sciences de la Terre et des Planètes* 325: 151–156.

Clist B (2006) Mais où se sont taillées nos pierres en Afrique Centrale entre 7.000 et 2.000 bp? In: Wotzka HP (ed.) *Grundlegungen. Beiträge zur europäischen und afrikanischen Archäologie für Manfred K.H. Eggert*. Tübingen: Francke Attempto Verlag GmbH and Co. KG, pp. 291–302.

Conedera M, Tinner W, Neff C et al. (2009) Reconstructing past fire regimes: Methods, applications, and relevance to fire management and conservation. *Quaternary Science Reviews* 28: 555–576.

Cornelissen E (2002) Human responses to changing environments in Central Africa between 40,000 and 12,000 BP. *Journal of World Prehistory* 16(3): 197–235.

De Lafontaine G and Payette S (2012) Long-term fire and forest history of subalpine balsam fir (*Abies balsamea*) and white spruce (*Picea glauca*) stands in eastern Canada inferred from soil charcoal analysis. *The Holocene* 22(2): 191–201.

De Maret P (1986) The Ngovo group: An industry with polished stone tools and pottery in Lower Zaire. *African Archaeological Review* 4(1): 103–133.

Denbow J (1990) Congo to Kalahari: Data and hypotheses about the political economy of the western stream of the Early Iron Age. *African Archaeological Review* 8: 39–176.

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

Dutoit T, Thinon M, Talon B et al. (2009) Sampling soil wood charcoals at a high spatial resolution: A new methodology to investigate the origin of grassland plant communities. *Journal of Vegetation Science* 20: 349–358.

Eckmeier E, Rösch M, Ehrmann O et al. (2007) Conversion of biomass to charcoal and the carbon mass balance from a slash-and-burn experiment in a temperate deciduous forest. *The Holocene* 17(4): 539–542.

Eggert MK (1992) The Central African rain forest: Historical speculation and archaeological facts. *World Archaeology* 24(1): 1–24.

Eggert MK, Höhn A, Kahlheber S et al. (2006) Pits, graves and grains: Archaeological and archaeobotanical research in southern Cameroon. *Journal of African Archaeology* 4(2): 273–298.

Elenga H, Schwartz D, Vincens A et al. (1996) Diagramme pollinique holocène du lac Kitina (Congo): mise en évidence de changements paléobotaniques et paléoclimatiques dans le massif forestier du Mayombe. *Comptes Rendus de l'Académie des Sciences, série IIA: Sciences de la Terre et des Planètes* 323: 403–410.

Engone Obiang NL, Ngomanda A, Hymas O et al. (2014) Diagnosing the demographic balance of two light-demanding tree species populations in central Africa from their diameter distribution. *Forest Ecology and Management* 313: 55–62.

Essomba JM (1998) L'archéologie de l'âge du fer au Cameroun méridional. In: Delneuf M, Essomba JM and Froment A (eds) *Paléo-anthropologie en Afrique centrale. Un bilan de l'archéologie au Cameroun*. Paris: L'Harmattan, pp. 233–247.

Fayolle A, Picard N, Doucet JL et al. (2014) A new insight in the structure, composition and functioning of central African moist forests. *Forest Ecology and Management* 329: 195–205.

Franqueville A (1973) *Atlas régional Sud-Ouest I. Échelles 1/500000 et 1/1 000000. République Unie du Cameroun*. Paris: ORSTOM.

Gavin DG (2001) Estimation of inbuilt age in radiocarbon ages of soil charcoal for fire history studies. *Radiocarbon* 43(1): 27–44.

Gavin DG, Brubaker LB and Lertzman KP (2003) Holocene fire history of coastal temperate rain forest based on charcoal radiocarbon dates. *Ecology* 84: 186–201.

Glaser B (2007) Prehistorically modified soils of central Amazonia: A model for sustainable agriculture in the twenty-first century. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 362: 187–196.

Glaser B, Balashov E, Haumaier L et al. (2000) Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Organic Geochemistry* 31: 669–678.

Glaser B, Haumaier L, Guggenberger G et al. (2001) The 'Terra Preta' phenomenon: A model for sustainable agriculture in the humid tropics. *Naturwissenschaften* 88: 37–41.

Gond V, Fayolle A, Pennec A et al. (2013) Vegetation structure and greenness in Central Africa from Modis multi-temporal data. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 368(1625): 20120309.

Hammond DS, ter Steege H and van der Borg K (2006) Upland soil charcoal in the wet tropical forests of central Guyana. *Biotropica* 39(2): 153–160.

Harms KE, Condit R, Hubbell SP et al. (2001) Habitat association of trees and shrubs in a 50-ha neotropical forest plot. *Journal of Ecology* 89: 947–959.

Hart TB, Hart JA, Dechamps R et al. (1996) Changes in forest composition over the last 4000 years in the Ituri basin, Zaire. In: Van der Maesen LJG, van der Burgt XM and van Medenbach de Rooy JM (eds) *The Biodiversity of African Plants*. Dordrecht: Springer, pp. 545–560.

Höhn A, Kahlheber S, Neumann K et al. (2008) Settling the rain forest: The environment of farming communities in southern Cameroon during the first millennium BC. *Palaeoecology of Africa* 28: 29–41.

Hubau W, Van den Bulcke J, Bostoen K et al. (2014) Archaeological charcoals as archives for firewood preferences and vegetation composition during the late-Holocene in the southern Mayumbe, Democratic Republic of the Congo (DRC). *Vegetation History and Archaeobotany* 23(5): 591–606.

Hubau W, Van den Bulcke J, Kitin P et al. (2012) Charcoal identification in species-rich biomes: A protocol for Central Africa optimised for the Mayumbe forest. *Review of Palaeobotany and Palynology* 171: 164–178.

Hubau W, Van den Bulcke J, Kitin P et al. (2013) Ancient charcoal as a natural archive for paleofire regime and vegetation change in the Mayumbe, Democratic Republic of Congo. *Quaternary Research* 80: 326–340.

Hubau W, Van den Bulcke J, Van Acker J et al. (2015) Charcoal-inferred Holocene fire and vegetation history linked to drought periods in the Democratic Republic of Congo. *Global Change Biology* 21(6): 2296–2308.

Kahlheber S, Bostoen K and Neumann K (2009) Early plant cultivation in the Central African rain forest: First millennium BC pearl millet from South Cameroon. *Journal of African Archaeology* 7(2): 253–272.

Kämpf N, Woods WI, Sombroek W et al. (2003) Classification of Amazonian dark earths and other ancient anthropic soils. In: Lehmann J, Kern DC, Glaser B et al. (eds) *Amazonian Dark Earths: Origin, Properties, Management*. Dordrecht: Kluwer Academic Publishers, pp. 77–102.

Kay AU and Kaplan JO (2015) Human subsistence and land use in sub-Saharan Africa, 1000 BC to AD 1500: A review, quantification, and classification. *Anthropocene* 9: 14–32.

Kearsley E, de Haulleville T, Hufkens K et al. (2013) Conventional tree height–diameter relationships significantly overestimate aboveground carbon stocks in the Central Congo Basin. *Nature Communications* 4: 2269.

Lanfranchi R, Ndanga J and Zana H (1998) New carbon ^{14}C datings of iron metallurgy in the Central African dense forest. In: Eves HE, Hardin R and Rupp S (eds) *Resource Use in the Trinational Sangha River Region of Equatorial Africa: Histories, Knowledge Forms, and Institutions* (Yale School of Forestry and Environmental Studies, vol. 102). New Haven, CT: Yale University, pp. 41–50.

Lavachery P (2001) The Holocene archaeological sequence of Shum Laka rock shelter (Grass fields, western Cameroon). *African Archaeological Review* 18(4): 213–247.

Lavachery P, MacEachern AS, Bouimon T et al. (2005) Komé to Ebomé: Archaeological research for the Chad Export Project, 1999–2003. *Journal of African Archaeology* 3(2): 175–194.

Letouzey R (1985) *Notice de la carte phytogéographique du Cameroun au 1: 500 000*. Toulouse: Institut de la carte internationale de la végétation.

Lézine AM and McKey D (2013) The impact of a major environmental crisis on species, populations and communities: The fragmentation of African forests at the end of the Holocene. *Comptes Rendus Géoscience* 345(7–8): 263–265.

Lézine AM, Holl AFC, Lebamba J et al. (2013) Temporal relationship between Holocene human occupation and vegetation change along the northwestern margin of the Central African rainforest. *Comptes Rendus Geoscience* 345(7): 327–335.

Logan AL and D'Andrea AC (2012) Oil palm, arboriculture, and changing subsistence practices during Kintampo times (3600–3200 BP, Ghana). *Quaternary International* 249: 63–71.

McMichael CH, Piperno DR, Bush MB et al. (2012) Sparse pre-Columbian human habitation in western Amazonia. *Science* 336: 1429–1431.

Maley J and Brenac P (1998) Vegetation dynamics, palaeoenvironments and climatic changes in the forests of western Cameroon during the last 28,000 years B.P. *Review of Palaeobotany and Palynology* 99: 157–187.

Maley J, Giresse P, Doumenge C et al. (2012) Comment on 'Intensifying weathering and land use in Iron Age Central Africa'. *Science* 337: 1040.

Martin D and Ségalen P (1966) *Carte Pédologique du Cameroun Oriental au 1/1000000*. Bondy: ORSTOM.

Mbida Mindzie C, Asombang R and Delneuf M (2001) Rescue archaeology in eastern Cameroon. *Antiquity* 75: 805–806.

Meister C (2008) Recent archaeological investigations in the tropical rain forest of south-west Cameroon. In: Runge J (ed.) *Dynamics of Forest Ecosystems in Central Africa during the Holocene: Past – Present – Future: Palaeoecology of Africa, an International Yearbook of Landscape Evolution and Palaeoenvironments*, vol. 28. Boca Raton, FL: CRC Press, pp. 43–57.

Meister C (2010) Remarks on early Iron Age burial sites from Southern Cameroon. *African Archaeological Review* 27: 237–249.

Moran PAP (1948) The interpretation of statistical maps. *Journal of the Royal Statistical Society, Series B: Methodological* 10: 243–251.

Morin-Rivat J, Fayolle A, Gillet JF et al. (2014) New evidence of human activities during the Holocene in the lowland forests of the northern Congo Basin. *Radiocarbon* 56: 209–220.

Neumann K, Bostoen K, Höhn A et al. (2012a) First farmers in the Central African rainforest: A view from southern Cameroon. *Quaternary International* 249: 53–62.

Neumann K, Eggert MKH, Oslisly R et al. (2012b) Comment on 'Intensifying weathering and land use in Iron Age Central Africa'. *Science* 337: 1040.

Neumer M, Becker E and Runge J (2008) Palaeoenvironmental studies in the Ngotto forest: Alluvial sediments as indicators of recent and Holocene landscape evolution in the Central African Republic. *Palaeoecology of Africa* 28: 121–137.

Ngomanda A, Neumann K, Schweizer A et al. (2009) Seasonality change and the third millennium BP rainforest crisis in southern Cameroon (Central Africa). *Quaternary Research* 71: 307–318.

Novák J, Sádlo J and Svobodová-Svitavská H (2012) Unusual vegetation stability in a lowland pine forest area (Doksy region, Czech Republic). *The Holocene* 22(8): 947–955.

Ohlson M and Tryterud E (2000) Interpretation of the charcoal record in forest soils: Forest fires and their production and deposition of macroscopic charcoal. *The Holocene* 10(4): 519–525.

Oslisly R (2001) The history of human settlement in the middle Ogooué Valley, Gabon: Implications for the environment. In: Weber W, White LJT, Vedder A et al. (eds) *African Rain*

Forest Ecology and Conservation: An Interdisciplinary Perspective. New Haven, CT: Yale University Press, pp. 101–118.
Oslisly R (2010) Une décennie d'archéologie de sauvetage et préventive au Cameroun (2000–2010). *Les Nouvelles de l'Archéologie* 120–121: 75–80.
Oslisly R and White LJT (2003) Étude des traces de l'impact de l'homme sur l'environnement au cours de l'Holocène dans deux régions d'Afrique centrale forestière: la réserve de la Lopé (Gabon central) et le sanctuaire du Banyang Mbo (Ouest-Cameroun). In: Froment A and Guffroy J (eds) *Peuplements anciens et actuels des forêts tropicales*. Paris: IRD, pp. 77–87.
Oslisly R, Bentaleb I, Favier C et al. (2013a) West Central African peoples: Survey of radiocarbon dates over the past 5000 years. *Radiocarbon* 55: 1377–1382.
Oslisly R, White LJT, Bentaleb I et al. (2013b) Climatic and cultural changes in the west Congo Basin forests over the past 5000 years. *Philosophical Transactions of the Royal Society of London, Series B: Biological Sciences* 368: 20120304.
Pessenda LCR, Gouveia SEM, Aravena R et al. (2004) Holocene fire and vegetation changes in southeastern Brazil as deduced from fossil charcoal and soil carbon isotopes. *Quaternary International* 114: 35–43.
Phillipson DW (2005) *African Archaeology*. Cambridge: Cambridge University Press.
Reimer PJ, Bard E, Bayliss A et al. (2013) IntCal13 and Marine13 radiocarbon age calibration curves, 0–50,000 years cal BP. *Radiocarbon* 55(4): 1869–1887.
Reynaud-Farrera I, Maley J and Wirrmann D (1996) Végétation et climat dans les forêts du Sud-Ouest Cameroun depuis 4770 ans BP: analyse pollinique des sédiments du Lac Ossa. *Comptes Rendus de l'Académie des Sciences, série IIA: Sciences de la Terre et des Planètes* 322: 749–755.
Robin V, Talon B and Nelle O (2013) Pedoanthracological contribution to forest naturalness assessment. *Quaternary International* 289: 5–15.
Robin V, Rickert BH, Nadeau MJ et al. (2011) Assessing Holocene vegetation and fire history by a multiproxy approach: The case of Stodthagen Forest (northern Germany). *The Holocene* 22(3): 337–346.
Runge J, Sangen M, Neumer M et al. (2014) Late Quaternary valley and slope deposits and their palaeoenvironmental significance in the Upper Congo Basin, Central Africa. *Palaeoecology of Africa* 32: 53–90.
Sanborn P, Geertsema M, Jull AJT et al. (2006) Soil and sedimentary charcoal evidence for Holocene forest fires in an inland temperate rainforest, east-central British-Columbia, Canada. *The Holocene* 16(3): 415–427.
Sangen M (2012) Late Quaternary palaeoenvironments in Southern Cameroon as evidenced by alluvial sediments from the tropical rain forest and savanna domain. *Palaeoecology of Africa* 31: 137–182.
Sangen M, Eisenberg J, Runge J et al. (2010) New findings from geological, geomorphological and sedimentological studies on the palaeoenvironmental conditions in Southern Cameroon. *Palaeoecology of Africa* 30: 166–188.
Schwartz D (1992) Assèchement climatique vers 3000 BP et expansion Bantu en Afrique Centrale atlantique: quelques réflexions. *Bulletin de la Société Géologique de France* 163(3): 353–361.
Scott AC (2000) The Pre-Quaternary history of fire. *Palaeogeography, Palaeoclimatology, Palaeoecology* 164: 281–329.
Scott AC (2010) Charcoal recognition, taphonomy and uses in palaeoenvironmental analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology* 291: 11–39.
Scott AC and Damblon F (2010) Charcoal: Taphonomy and significance in geology, botany and archaeology. *Palaeogeography, Palaeoclimatology, Palaeoecology* 291(1): 1–10.
Talon B (2010) Reconstruction of Holocene high-altitude vegetation cover in the French southern Alps: Evidence from soil charcoal. *The Holocene* 20(1): 35–44.
Tardy C, Vernet J-L, Servant M et al. (2000) Feux, sols et écosystèmes forestiers tropicaux. In: Servant-Vilardy S (ed.) *Dynamique à long terme des écosystèmes forestiers intertropicaux*. Paris: UNESCO, pp. 343–348.
Théry-Parisot I, Chabal L and Chrzavzez J (2010) Anthracology and taphonomy, from wood gathering to charcoal analysis. A review of the taphonomic processes modifying charcoal assemblages, in archaeological contexts. *Palaeogeography, Palaeoclimatology, Palaeoecology* 291: 142–153.
Thinon M (1978) La pédoanthracologie: une nouvelle méthode d'analyse phytochronologique depuis le Néolithique. *Comptes Rendus de l'Académie des Sciences de Paris, série D* 287: 1203–1206.
Titiz B and Sanford RL, Jr (2007) Soil charcoal in old-growth rain forests from sea level to the continental divide. *Biotropica* 39(6): 673–682.
Touflan P and Talon B (2009) Spatial reliability of soil charcoal analysis: The case of subalpine forest soils. *Écoscience* 16(1): 23–27.
Touflan P, Talon B and Walsh K (2010) Soil charcoal analysis: A reliable tool for spatially precise studies of past forest dynamics: A case study in the French southern Alps. *The Holocene* 20(1): 45–52.
Tovar C, Breman E, Brncic T et al. (2014) Influence of 1100 years of burning on the central African rainforest. *Ecography* 37: 1139–1148.
Van Gemerden BS, Olff H, Parren MPE et al. (2003) The pristine rain forest? Remnants of historical human impacts on current tree species composition and diversity. *Journal of Biogeography* 30: 1381–1390.
Vennetier P (1963) *Les hommes et leurs activités dans le nord du Congo-Brazzaville*. PhD Dissertation, University of Bordeaux.
Vermeulen C and Karsenty A (2001) Place et légitimité des terroirs villageois dans la conservation. In: Delvingt W (ed.) *La forêt des hommes: terroirs villageois en forêt tropicale africaine*. Gembloux: Presses Agronomiques de Gembloux, pp. 217–234.
Vincens A, Buchet G, Servant M et al. (2010) Vegetation response to the 'African Humid Period' termination in Central Cameroon (7° N) – New pollen insight from Lake Mbalang. *Climate of the past* 6: 281–294.
Vincens A, Schwartz D, Elenga H et al. (1999) Forest response to climate changes in Atlantic Equatorial Africa during the last 4000 years BP and inheritance on the modern landscapes. *Journal of Biogeography* 26: 879–885.
Vleminckx J, Morin-Rivat J, Biwolé AB et al. (2014) Soil charcoal to assess the impacts of past human disturbances on tropical forests. *PLoS ONE* 9(11): e108121.
Whitlock C and Larsen C (2001) Charcoal as a fire proxy. In: Smol JP, Birks HJB and Last WM (eds) *Tracking Environmental Change Using Lake Sediments. Volume 3: Terrestrial, Algal, and Siliceous Indicators*. Dordrecht: Kluwer Academic Publishers, pp. 75–97.
Willis MKJ, Gillson L and Brncic TM (2004) How 'virgin' is virgin rainforest? *Science* 304: 402–403.
Wotzka HP (2006) Records of activity: Radiocarbon and the structure of Iron Age settlement in Central Africa. In: Wotzka HP (ed.) *Grundlegungen. Beiträge zur europäischen und afrikanischen Archäologie für Manfred K.H. Eggert*. Tübingen: Francke Attempto Verlag GmbH and Co. KG, pp. 271–289.