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ORIGINAL ARTICLE

Archaeological charcoals as archives for firewood preferences and vegetation composition during the late Holocene in the southern Mayumbe, Democratic Republic of the Congo (DRC)

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Abstract Analysis of charcoal from an archaeological assemblage near the Lukula community located at the southernmost boundary of the Mayombe forest (Bas-Congo, DRC) yielded 30 taxa used as firewood between 1,200 and 700 cal. B.P. Local people mentioned 71 taxa preferred for use nowadays. The identified taxa belong either to mature rainforest, pioneer forest, regenerating forest or woodland savanna, indicating that ancient and current local populations gathered firewood in several different forest types. Modern firewood preferences do not seem to agree with the archaeobotanical composition. Also, linguistic evidence does not indicate a long exploitation history for all of the recorded taxa. Furthermore, no particular wood qualities such as wood density, calorific value or magical or medicinal properties seem to determine the Lukula assemblage, which was probably composed of waste material from various activities which required different specific firewood characteristics. As such, taxa composition is not biased by human selection, suggesting that it reflects the surrounding environment, which was characterised by mature rainforest with patches of regenerating forest and open vegetation types. Unlike the origin of present-day forest-savanna mosaics from human activity, fragmentation around 1,000 cal. B.P. may have been provoked by a well-known climatic event coinciding with the Medieval Climate Anomaly, which undoubtedly had a significant impact on Central African forest composition.

Keywords Firewood preference · Charcoal identification · Central Africa · Forest fragmentation · Archaeobotany

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Introduction

Perhaps the most persistent matter of debate about Holocene Central African forest dynamics is the relative contributions of climate and human impact (Brncic et al. 2007, 2009; Bayon et al. 2012; Neumann et al. 2012b; Maley et al. 2012). There are significant uncertainties in our knowledge of the relationship between human populations and their environment during the Holocene. Archaeological data from Central Africa can be described as 'few and far between', rather thin and patchy compared to other parts of the world (Van Noten 1982; Lanfranchi and Clist 1991; Oslisly 1992; Wotzka 1990; Assoko Ndong 2001; Elouga

2001; Clist 2005; Eggert 2005; Matoumba 2008; Gouem Gouem 2011). In addition, pollen is generally poorly preserved at archaeological sites in the region. Therefore, other indices of human–environment relationships have been explored, such as analyses of phytoliths, charcoal and seeds (Pinçon 1990; Mercader et al. 2003; Neumann et al. 2012a). However, these disciplines are still in their infancy in Central Africa. As a result, we know little about agricultural practices or firewood selection, for example for cooking or for craft, and about how they can be identified in sedimentary records.

Seed remains (carpology) have been used to demonstrate human subsistence strategies (Neumann et al. 2012a), but firewood remains have only been studied sporadically (Pinçon 1990; Lavachery 2001; Eggert et al. 2006; Picornell-Gelabert et al. 2011), despite the abundance of charcoal fragments in archaeological layers and the prominent role of forests, trees and wood in the daily life of local communities in the Central African rainforest. Charcoal analysis in tropical environments is complicated by species richness, synonymy and the scarcity of digitized databases. Recent development of a semi-automatic procedure for the identification of Central African charcoals has tackled these problems (Hubau et al. 2012). The protocol has been applied to pedoanthracological (non-archaeological soil charcoal) assemblages to reconstruct wildfire and vegetation dynamics of the Luki reserve, situated in the Mayumbe forest, which is the southernmost part of the Lower Guinean rainforest complex (Hubau et al. 2013). Such pedoanthracological assemblages give a detailed view of past fire regimes and vegetation changes on an appropriately small spatial scale, but cannot fully reveal the possible role of humans.

In this paper we report on an excavation that was conducted near the present Lukula community, situated at the edge of the Mayumbe forest, Bas-Congo, DRC (Fig. 1). In contrast to the excavations conducted in mature rainforest relicts in the Luki reserve (Hubau et al. 2013), the Lukula excavation yielded significant amounts of pottery, iron slag and charcoal fragments which were most probably remains of firewood. The main objective of this manuscript is to illustrate how charcoal evidence from archaeological sites in Lower Guinea can contribute to our understanding of past interactions between humans and their environment. Specific research questions addressed in this manuscript are: (1) From which environment was firewood gathered by ancient communities in Lower Guinea? (2) Were there any preferences with regard to firewood characteristics? (3) Do the firewood preferences differ between ancient and modern communities? (4) Can forest type reconstructions from an archaeobotanical assemblage contribute to the understanding of past climatic conditions in Lower Guinea?

Materials and methods

Study site and charcoal sampling

The Mayumbe hills stretch along the Atlantic coast from western Gabon down to the Bas-Congo province of the Democratic Republic of Congo (DRC) (Fig. 1). The hills are covered by semi-deciduous rainforest, which was the dominant land cover, probably even during severe climate anomalies such as the last glacial maximum (Sosef 1996), although the forest boundaries are thought to be sensitive to climate change (Maley 1996). The studied site is situated in the vicinity of the present Lukula community, near the edge of a small plateau or flat hilltop (Fig. 1; 5°26′6.96″ S; 12°57′41.7″ E). As for all other sampling sites for an ongoing ancient charcoal study in the Mayumbe (Hubau et al. 2012, 2013), a relatively flat area was chosen, avoiding steep slopes to minimize the effects of erosion or deposition of colluvium (Carcaillet and Thinon 1996). The excavation for soil charcoal in an area of 100 × 150 cm^2 was conducted on a spot where prospection with an Edelman auger yielded charcoal at depths down to 40 cm and where the soil was relatively dry and penetrable. Artefacts and charcoal fragments (largest width >2 mm) were carefully collected by hand at an interval of 10 cm. Specific charcoal mass was calculated as described by Carcaillet and Thinon (1996). Thin sections were prepared for undisturbed soil samples, following polyester

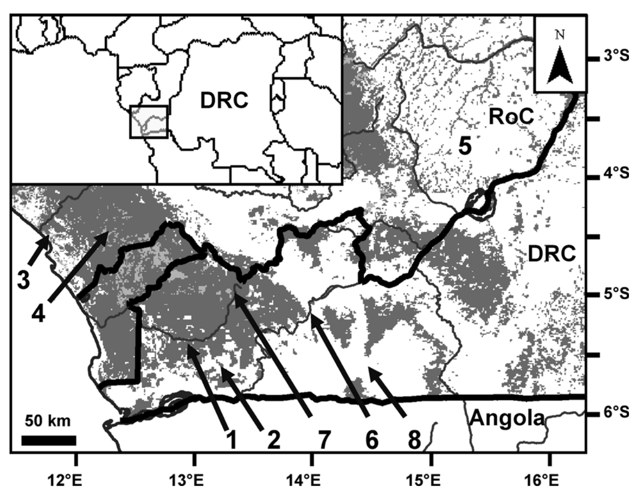

Fig. 1 Geographical setting of the study site, the Luki reserve and the other sites mentioned in the text. *Dark grey* current mature rainforest cover, *light grey* regenerating forest, *DRC* Democratic Republic of Congo, *RoC* Republic of Congo, *1* Lukula profile, *2* Luki reserve (Hubau et al. 2013), *3* Tchissanga (Clist 2005, 2012; Denbow 2012), *4* La mare du Flec (Schwartz et al. 1990; De Foresta 1990), *5* Teke uplands (Pinçon 1990; Dupre and Pinçon 1997), *6* Sakusi (Gosselain 1988; Kanimba Misago 1991; Clist 2005, 2012), *7* Sumbi (Clist 2012), *8* Mbafu (Clist 2012)

impregnation using standard procedures (Murphy 1986) and micromorphological features were described using polarisation microscopy, and the concepts and terminology of Stoops (2003).

Charcoal identification and evaluation of identification reliability

For each 10 cm profile interval, up to 50 charcoal fragments were analysed using reflected light microscopy (RLM) and grouped into charcoal types, from which each represents a group of taxa matching the charcoal anatomy (Hubau et al. 2012). Next, a large fragment of each charcoal type was mounted on a stub for scanning electron microscopy (SEM). Based on SEM images, charcoal types were described with the same numbered anatomical features as used for the on-line InsideWood database (IAWA Committee 1989; Wheeler 2011; InsideWood 2011; Hubau et al. 2012; Hubau 2013). The final result of the charcoal type description consists of two strings of numbered features. A first string represents primary features which are easily visible and the second string represents secondary features which are variable or unclear.

All charcoal types were identified applying a semi-automatic four-step protocol for central African charcoal identification, using the string of primary anatomical features (Hubau et al. 2012; Hubau 2013). The identification protocol is developed within an umbrella database of species names and metadata, compiled from an on-line database of wood-anatomical descriptions (InsideWood 2011), the database of the world's largest reference collection of central African wood specimens (RMCA, Tervuren, Belgium), and inventory and indicator species lists. The protocol starts with an anatomical query within this database, focussing on genus rather than species level, proceeds with automatic extension and reduction phases of the resulting species list and ends with a comparative microscopic study of wood reference thin sections and charcoal anatomy. During the last phase, both primary and secondary anatomical charcoal features are taken into account.

For each charcoal type, the final result of identification is a group of woody species, which are ranked according to their resemblance to the charcoal type anatomy (Hubau et al. 2012). Specifically, a five-point grading system was used, whereby five points are attributed in the case of perfect agreement between charcoal anatomy and woody species anatomy. This grading is subject to the user's opinion and is performed during the last phase of the protocol, when reference material is compared to the charcoal type anatomy. The charcoal type receives a nine-character label consisting of the three first letters of family, genus and species name of one of the best ranked species (Hubau et al. 2012).

Next, all charcoal types are evaluated according to two criteria. Evaluation criterion 'a' reflects whether the highest ranked species have similar phytosociological characteristics. Evaluation criterion 'b' is based on the number of highest ranked species and their anatomy rank, with a higher score for increasing degree of resemblance between charcoal and wood anatomy. Based on both criteria, the charcoal type is assigned to one of six identification reliability ranks, which allows a distinction between strong and weak identifications.

Profile stratigraphy and radiocarbon dating

Possible profile stratigraphy, suggested by vertical distribution patterns of artefacts, charcoal mass and charcoal types, was verified using constrained and unconstrained cluster analysis, performed with the R package Rioja, developed for the analysis of stratified patterns in palaeorecords (Juggins 2012). Statistically different profile depth zones were demarcated by optimal sum-of-squares zonation (Birks and Gordon 1985), using the broken-stick model (Bennett 1996). From each stratigraphic interval, a charred endocarp fragment and a wood-derived charcoal fragment were randomly selected for AMS ^{14}C dating at the Poznán Radiocarbon Laboratory (Poland) or Beta Analytic (Florida, USA). Calibration was performed with the Calib 6.1.0 software package (Stuiver and Reimer 1993; Stuiver et al. 2005) using the SHCal04 southern hemisphere atmospheric curve (McCormac et al. 2004).

Firewood characterization

As all highest ranked species for a certain charcoal type have similar anatomical characteristics, one can assume that firewood characteristics are also similar. Therefore a representative woody species was selected from the highest ranked species of each charcoal type which resembled the wood anatomy of one or more species almost perfectly (anatomy rank 5). For each selected species, two wood specimens were selected from the reference collection of the Royal Museum for Central Africa (Tervuren Xylarium Wood Database 2012). From each wood sample, a rectangular prismatic subsample of approximately 50 cm^3 was sawn and the exact dimensions were measured with a caliper for volume calculation. These samples were then dried for 2 h at 60 °C, 4 h at 80 °C and finally 48 h at 103 °C (Maniatis et al. 2011). The samples were weighed for oven-dry density calculations and ground. Higher Heating Values (HHV, in MJ) were measured for 0.4–0.5 g of ground oven-dried material using an isoperibolic bomb calorimeter (Parr Instruments).

Modern firewood preference survey

In five villages near the Luki Biosphere Reserve (Fig. 1), a group of ten respondents was asked about their preferred firewood for modern use. After mutual discussion, each group unanimously reported their top ten most preferred wood taxa. For all wood taxa mentioned by the respondents, the names were given in Kiyombe, the Bantu language spoken in the southern Mayumbe. The names of the top ten and those of the taxa that were also retained after identification of one of the charcoal types found in the Lukula profile were compared to the names of the same species in other West African Bantu languages in order to assess whether these species have widespread cognate terms in Lower Guinea. If so, it can be assumed that the species were already known and possibly used by Bantu-speaking migrants before their arrival in southern Mayumbe (Bostoen 2005, 2013; De Grauwe 2009; Bostoen et al. 2013).

Results

Artefacts and charcoal mass

Figure 2 presents profile information, the number of artefacts per interval and specific charcoal mass per interval (ppm). In total, eight iron slag fragments and 128 pottery fragments were found, including two that were larger than 5 cm. Some aspects of this archaeological assemblage indicate possible profile stratification. Firstly, there was an artefact-free layer between 50 and 70 cm depth, and pottery fragments from the upper intervals (0–10 to 40–50 cm) could not be refitted with those of the deeper intervals (70–80 to 130–140 cm). Also, iron slag was only found in the upper 50 cm. Finally, the potsherds in the upper intervals were strongly weathered, compared to the more pristine condition of those in the lower intervals. This can be explained by longer exposure to surface and near-surface conditions, which are harsh in humid tropical environments.

On the other hand, the profile includes no charcoal-free intervals, as illustrated by the specific charcoal mass diagram (Fig. 2). Down to 80 cm depth, all intervals yielded more than 20 ppm charcoal, which is a high concentration compared to charcoal assemblages from natural forest fires in the Luki reserve (Hubau et al. 2013). This upper part with high charcoal values (0–80 cm) was separated from a minor peak in charcoal content for the 90–100 cm interval (14 ppm) by the relatively charcoal-poor 80–90 cm interval. However, this interval still yielded 9 ppm charcoal, which is not negligible. This suggests that the charcoal assemblage is the result of continuous deposition rather than being from two separate events.

Profile development

The relatively low concentration of artefacts suggests that the excavation did not encounter an ancient refuse pit, where pottery sherds are often found in large numbers, but was excavated rather in between refuse pits or within the territory of an ancient iron-smelting community. Scattered fragments

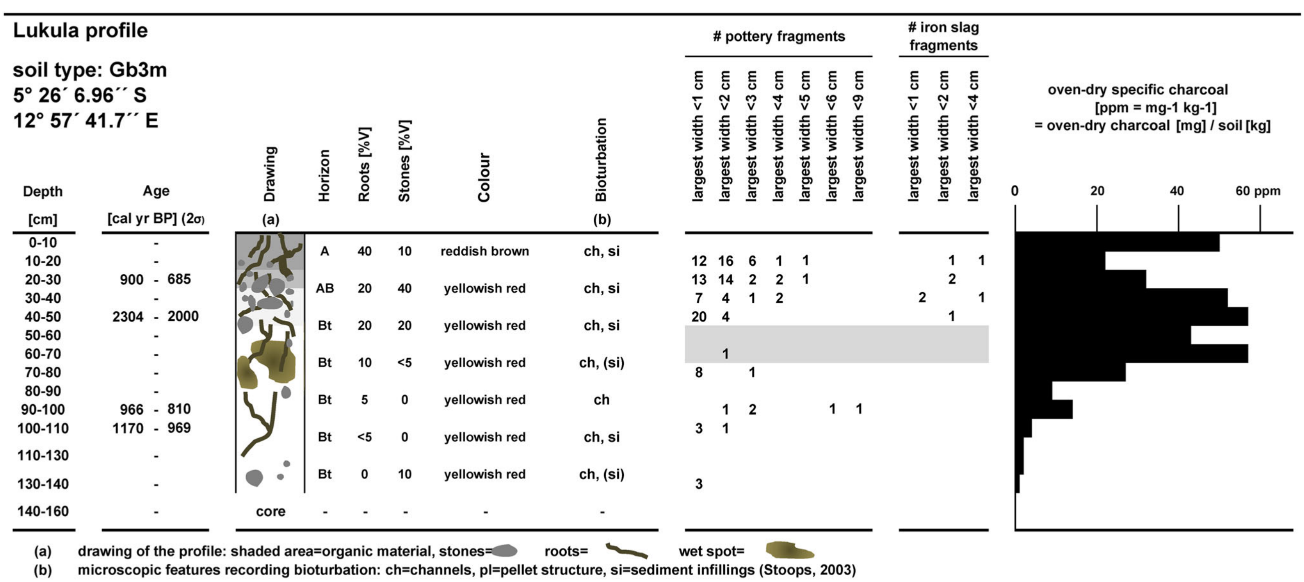

Fig. 2 Profile description and distribution of artefacts (pottery fragments and iron slag) and charcoal mass throughout the profile. The *grey shade* in the pottery fragments and iron slag columns indicates an artefact-free interval (50–70 cm) separating two distinctly different artefact assemblages

of charcoal, iron slag and pottery may have been moved deeper down the soil under a community floor due to human passage in a first phase, and due to soil disturbance in a second phase. Soil thin sections show common fine clay coatings below 40 cm depth, compatible with Bt horizon development. Indeed, the Lukula profile was excavated in an area dominated by soils with ABtC profiles on gneissic or granitic parent materials, according to the soil map of the Bas-Congo region (Fig. 2, Gb3m; Van Ranst et al. 2010), corresponding to Acrisols in the WRB system (Baert 1995). Soil thin sections also show common channels in all samples, partly with aggregates of groundmass material as infillings, as well as pervasive fragmentation of illuvial clay coatings in the 20–40 cm interval. The abundant channels and associated features indicate strong bioturbation throughout the profile (Fig. 2; Stoops 2003). Various types of soil fauna, including ants and termites are very abundant and active in tropical environments, down to the water table (McBrearty 1990; Théry-Parisot et al. 2010).

Radiocarbon dates

Four charcoal fragments have been dated (Fig. 3). Three dates are obviously in agreement. Charcoal from the deepest levels (90–110 cm) is dated at 1,143–902 cal. B.P. (Beta-329504, Poz-33006), which can be extended to 811 cal. B.P. with a rather low probability of 21 %. The uppermost interval yields an age that is slightly younger (803–717 cal. B.P.). However, the date obtained for an intermediate interval is between 2,162 and 1,999 cal. B.P. (81 % probability) or even older (2,302–2,242 cal. B.P., 18 % probability), which is at least 850 years older than the other three dates. This older date was obtained from a charcoal sample identified as *Milicia excelsa*. Trees of this species are often considered as sacred, and they are therefore frequently protected and planted in villages and farmlands, where they can grow relatively old (Koni Muluwa and Bostoen 2010; Protabase 2012). As such, one could suggest that the charcoal fragment originated from the oldest year rings of a very old (>850 years) specimen. However, it is not yet clear if and how frequently tropical trees reach such ages (Worbes and Junk 1999).

More likely, the ancient occurrence can be explained by a mixing process that added older charcoal fragments to the assemblage. As there is no other evidence for the occurrence of an earlier occupation level on this site, the older charcoal fragment is likely the result of a natural forest fire in the vicinity of the profile site between 2,300 and 2,000 cal. B.P. A charcoal assemblage of the same age has been found in a forest stand in the neighbouring Luki reserve (Hubau et al. 2012, 2013). Occurrences of soil charcoal assemblages dating back to 3,000–2,000 cal. B.P. have also been reported for the Ituri forest, DRC (Hart et al. 1996). These assemblages originated either from natural or from human-induced fires.

Soils in villages are often disturbed, for instance for crop cultivation, latrines or house building. This type of disturbance in the direct vicinity of the hillcrest could have caused buried charcoal fragments to become exposed along the surface, from where they could have moved laterally and become mixed with a younger assemblage on the community floor. Evidence from the Luki reserve shows that charcoal assemblages originating from ancient fires can be found in the upper 20 cm of soil profiles at some sites (Hubau et al. 2012, 2013). An alternative explanation is bioturbation, which was a significant process at the Lukula site, as shown

Depth [cm]	Charcoal type	Representative species	Lab. nr. & ^{14}C age	2σ calibrated age ranges [cal yr BP]	Probability [%]
20-30	Drupe endocarp	*Elaeis guineensis*	Beta-329503	899 - 873	5,9
			900 ± 30	803 - 717	90,4
				705 - 686	3,7
40-50	MOR MIL EXC	cfr. *Milicia excelsa*	Beta-324748	2302 - 2242	17,6
		(mature wood)	2190 ± 30	2179 - 2167	1,7
				2162 - 1999	80,7
90-100	CAE APH SPP	cfr. *Aphanocalyx microphyllus*	Poz-33006	966 - 902	79,2
		(mature wood)	1060 ± 30	868 - 811	20,8
100-110	Drupe endocarp	*Elaeis guineensis*	Beta-329504	1169 - 1159	3
			1200 ± 30	1143 - 969	97

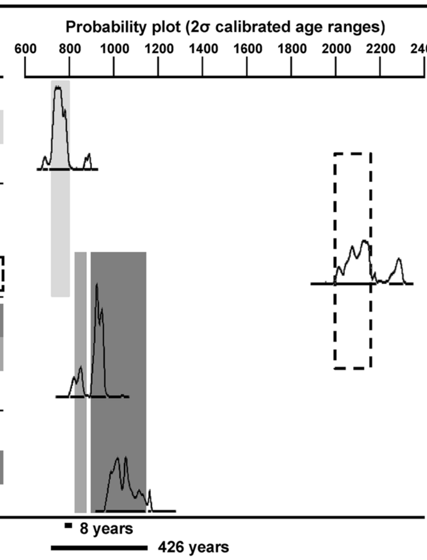

Fig. 3 Conventional radiocarbon ages and calibrated ages

Table 1 The charcoal types and their scores for identification reliability, highest ranked species, phytosociological and morphological characteristics of the highest ranked species (× present; − absent)

Type	Evaluation: (a) Propinquity	Evaluation: (b) Species resemblance	Evaluation: (c) Reliability rank (/6)	Highest ranked species		Anatomy rank (/5)	Phytosociology: Evergreen rainforest	Phytosociology: Regenerating forest	Phytosociology: Margin forest-savanna	Phytosociology: Woodland savanna	Morphology: High tree (>20m)	Morphology: Small tree (5-20m)	Morphology: Shrub (0-5m)	Morphology: Liana
ANA PSE MIC	+	+++	1	Anacardiaceae	*Pseudospondias microcarpa* (A. Rich.) Engl.	5	x	?	x	-	-	x	x	-
APO ALS SPP	+	+++	1	Apocynaceae	*Alstonia boonei* De Wild.	5	x	x	-	-	x	-	-	-
				Apocynaceae	*Alstonia congensis* Engl.	5	x	?	-	-	x	x	-	-
BUR CAN SCH	+	+++	1	Burseraceae	*Canarium schweinfurthii* Engl.	5	x	x	-	-	x	-	-	-
				Burseraceae	*Aucoumea klaineana* Pierre	5	x	x	-	-	x	-	-	-
CLU MAM AFR	+	+++	1	Clusiaceae	*Mammea africana* Sabine	5	?	-	-	-	x	-	-	-
EUP MAR MIC	+	+++	1	Euphorbiaceae	*Mareya micrantha* (Benth.) Müll. Arg.	5	x	x	-	-	-	x	x	-
MOR MIL EXC	+	+++	1	Moraceae	*Milicia excelsa* (Welw.) C.C. Berg	5	x	x	x	x	x	-	-	-
MOR MUS CEC	+	+++	1	Moraceae	*Musanga cecropioides* R. Br. ex Tedlie	5	x	x	-	-	x	-	-	-
MYR RAP MEL	+	+++	1	Myrsinaceae	*Rapanea melanophloeos* (L.) Mez	5	-	-	x	x	-	x	x	-
PAS PAR GRE	+	+++	1	Passifloraceae	*Paropsia grewioides* Welw. ex Mast.	5	?	x	x	-	-	-	x	-
IRV IRV GAB	+	++	1	Irvingiaceae	*Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	5	x	-	-	-	x	-	-	-
				Irvingiaceae	*Irvingia grandifolia* (Engl.) Engl.	5	-	-	-	-	x	-	-	-
				Irvingiaceae	*Irvingia wombolu* Vermoesen	5	x	-	-	-	x	x	-	-
MYR PYC ANG	+	++	1	Myristicaceae	*Pycnanthus angolensis* (Welw.) Exell	5	x	x	-	-	x	x	-	-
				Myristicaceae	*Pycnanthus marchalianus* Ghesq.	5	x	x	-	-	x	x	-	-
				Myristicaceae	*Scyphocephalium mannii* (Benth.) Warb.	5	x	x	-	-	x	x	-	-
PAN MIC SPP	+	++	1	Pandanaceae	*Microdesmis haumaniana* J. Léonard	5	x	x	-	-	-	-	x	-
				Pandanaceae	*Microdesmis kasaiensis* J. Léonard	5	x	-	-	-	-	x	x	-
				Pandanaceae	*Microdesmis puberula* Hook. f. ex Planch.	5	?	x	-	-	-	-	x	-
				Pandanaceae	*Microdesmis yafungana* J. Léonard	5	x	-	-	-	-	x	x	-
SAP PAN SPP	+	++	1	Sapindaceae	*Aporrhiza paniculata* Radlk.	5	x	?	x	-	-	x	-	-
				Sapindaceae	*Pancovia floribunda* Pellegr.	5	x	-	-	-	-	-	x	-
				Sapindaceae	*Pancovia harmsiana* Gilg	5	x	-	-	-	-	x	x	-
				Sapindaceae	*Pancovia laurentii* (De Wild.) Gilg ex De Wild.	5	x	-	-	-	x	x	-	-
				Sapindaceae	*Pancovia turbinata* Radlk.	5	x	-	-	-	-	-	x	-
				Sapindaceae	*Placodiscus resendeanus* Exell & Mendonça	5	x	-	-	-	-	-	x	-
ANN NEO GAB	+	+	2	Annonaceae	*Neostenanthera gabonensis* (Engl. & Diels) Exell	4	x	-	-	-	-	?	x	-
ANN XYL AET	+	+	2	Annonaceae	*Xylopia aethiopica* (Dunal) A. Rich.	4	x	x	x	?	x	x	-	-
PAP CAM SCA	+	+	2	Papilionoideae	*Aganope lucida* (Welw. ex Baker) Polhill	4	x	x	x	-	-	-	-	x
				Papilionoideae	*Camoensia scandens* (Welw.) J.B. Gillett	4	x	x	x	x	-	-	-	x
CAE APH SPP	+	-	2	Caesalpinioideae	*Aphanocalyx microphyllus* (Harms) Wieringa	4	x	?	x	-	x	-	-	-
				Caesalpinioideae	*Bikinia durandii* (F.Hallé & Normand) Wieringa	4	x	-	-	-	x	-	-	-
				Caesalpinioideae	*Bikinia letestui* (Pellegr.) Wieringa	4	x	x	-	-	x	-	-	-
				Caesalpinioideae	*Aphanocalyx heitzii* (Pellegr.) Wieringa	4	x	?	x	-	x	-	-	-
PAP MIL SPP	+	-	2	Papilionoideae	*Millettia drastica* Welw. ex Baker	4	?	x	x	x	x	x	-	-
				Papilionoideae	*Millettia laurentii* De Wild.	4	?	?	x	x	x	x	-	-
				Papilionoideae	*Millettia macroura* Harms	4	?	x	x	x	-	?	x	x
				Papilionoideae	*Millettia versicolor* Welw. ex Baker	4	x	x	x	x	-	?	x	x
PHY BRI FER	+	-	2	Phyllantaceae	*Bridelia ferruginea* Benth.	4	-	x	x	x	-	-	x	-
				Phyllantaceae	*Bridelia brideliifolia* (Pax) Fedde	4	x	x	x	?	x	x	-	-
				Rubiaceae	*Ancylanthos rubiginosus* Desf.	4	-	-	-	x	-	-	x	-
SAP CHR SPP	+	-	2	Sapotaceae	*Chrysophyllum gorungosanum* Engl.	4	x	-	-	-	x	-	-	-
				Sapotaceae	*Chrysophyllum pruniforme* Pierre ex Engl.	4	x	-	-	-	x	-	-	-
				Sapotaceae	*Chrysophyllum perpulchrum* Mildbr. ex Hutch. & Dalziel	4	?	-	-	-	x	-	-	-
				Sapotaceae	*Pouteria pierrei* (A. Chev.) E.O. Beal	4	?	?	?	?	?	?	?	-
				Sapotaceae	*Chrysophyllum giganteum* A.Chev.	4	x	-	-	-	x	-	-	-

Data on phytosociology and morphology are derived from African Plants Database (2012), Lebrun and Gilbert (1954), Protabase (2012), Burkill (1985) and Leal (2004)

by features observed in soil thin sections (Fig. 2). As such, bioturbation can explain both the strong vertical scatter of artefacts and the ^{14}C date discrepancies (see also Schwartz and Gebhardt 2011; Clist et al. in press).

Charcoal identifications

The phytosociology and morphology of the highest ranked taxa for each charcoal type are presented in Table 1. For each charcoal type a 4-page 'ID card' has been prepared and presented by Hubau (2013), which contains descriptions, a table with metadata of the retained taxa (cf. Table 1), a discussion of identification reliability and a conclusion regarding the assignment to a vegetation type. Moreover, the ID cards present SEM images of the charcoal anatomy and images of reference material as a comparison.

Figure 4 shows the distribution of 586 analysed charcoal fragments throughout the profile and the charcoal types to

Table 1 continued

Type	Evaluation: (a) Propinquity	Evaluation: (b) Species resemblance	Evaluation: (c) Reliability rank (/6)	Highest ranked species		Anatomy rank (/5)	Phytosociology: Evergreen rainforest	Phytosociology: Regenerating forest	Phytosociology: Margin forest-savanna	Phytosociology: Woodland savanna	Morphology: High tree (>20m)	Morphology: Small tree (5-20m)	Morphology: Shrub (0-5m)	Morphology: Liana
				Apocynaceae	*Voacanga africana* Stapf	5	?	x	x	x	-	x	x	-
				Apocynaceae	*Voacanga chalotiana* Pierre ex Stapf	5	?	x	?	?	?	?	?	?
APO VOA SPP	-	++	4	Apocynaceae	*Voacanga thouarsii* Roem. & Schult.	5	-	-	x	x	-	x	-	-
				Apocynaceae	*Tabernaemontana brachyantha* Stapf	5	x	?	-	-	-	x	-	-
				Apocynaceae	*Tabernaemontana africana* A. DC.	5	-	?	-	x	-	x	x	-
				Caesalpinioideae	*Cynometra lujae* De Wild.	5	x	x	?	-	-	x	-	-
CAE CYN SES	-	++	4	Caesalpinioideae	*Cynometra sessiliflora* Harms	5	x	-	-	-	-	x	x	-
				Caesalpinioideae	*Hymenostegia floribunda* (Benth.) Harms	5	x	-	-	-	-	x	x	-
				Caesalpinioideae	*Cynometra ananta* Hutch. & Dalziel	5	x	-	-	-	x	-	-	-
				Chrysobalanaceae	*Parinari congensis* Didr.	5	x	-	?	-	x	-	-	-
CHR PAR SPP	-	++	4	Chrysobalanaceae	*Parinari curatellifolia* Planch. ex Benth.	5	-	x	x	x	-	x	-	-
				Chrysobalanaceae	*Parinari excelsa* Sabine	5	x	-	?	-	x	-	-	-
				Chrysobalanaceae	*Parinari hypochrysea* Mildbr. ex Letouzey & F. White	5	x	-	?	-	x	-	-	-
				Caesalpinioideae	*Berlinia bracteosa* Benth.	4	x	x	x	-	x	-	-	-
				Caesalpinioideae	*Berlinia confusa* Hoyle	4	x	?	-	-	x	-	-	-
CAE BER SPP	-	-	5	Caesalpinioideae	*Berlinia giorgii* De Wild.	4	-	?	x	x	-	x	x	-
				Caesalpinioideae	*Berlinia viridicans* Baker f.	4	x	-	-	-	-	x	x	-
				Caesalpinioideae	*Peltophorum africanum* Sond.	4	-	?	x	x	-	x	x	-
				Moraceae	*Ficus ottoniifolia* (Miq.) Miq.	4	x	x	x	-	-	-	x	x
				Moraceae	*Ficus ovata* Vahl	4	x	-	x	x	x	x	-	-
MOR FIC SPP	-	-	5	Moraceae	*Ficus preussii* Warb.	4	x	x	x	-	-	x	x	-
				Moraceae	*Ficus sansibarica* Warb.	4	x	-	x	x	-	x	x	-
				Moraceae	*Ficus wildemaniana* Warb.	4	x	-	x	-	-	x	x	-
				Moraceae	*Ficus thonningii* Blume	4	-	?	-	x	-	x	x	-

RELIABILITY EVALUATION CRITERIA :

		# types	% types
(a) phytosociological propinquity			
+	highest ranked species have similar habitat preferences	20	80
-	highest ranked species have different habitat preferences	5	20
(b) woody species resemblance			
+++	almost perfect resemblance with only one or two (highest anatomy rank = 5/5)	9	36
++	almost perfect resemblance with more than two (highest anatomy rank = 5/5)	7	28
+	good resemblance with only one or two (highest anatomy rank = 4/5)	3	12
-	good resemblance with more than two (highest anatomy rank = 4/5)	6	24
--	only moderate resemblance with one or more (highest anatomy rank = 3/5 or less)	0	0
(c) RELIABILITY RANK :			
1	phytosociological propinquity (crit. a) & almost perfect resemblance (crit. b)	13	52
2	phytosociological propinquity & very good resemblance	7	28
3	phytosociological propinquity & only moderate resemblance	0	0
4	phytosociological ambiguity & almost perfect resemblance	3	12
5	phytosociological ambiguity & very good resemblance	2	8
6	phytosociological ambiguity & only moderate resemblance	0	0

Data on phytosociology and morphology are derived from African Plants Database (2012), Lebrun and Gilbert (1954), Protabase (2012), Burkill (1985) and Leal (2004)

which they belong. Many of them were derived from *Elaeis guineensis* (oil palm) drupes. Twenty five charcoal types were derived from mature wood and could be identified. In addition, a few types that were recognized could not be identified, namely a mature hardwood type whose anatomical features were too unclear due to fire cracks, a juvenile wood type that consisted mainly of pith tissue, an unidentifiable organic tissue fragment, and three monocotyledon types which were not identifiable with a charcoal identification protocol based on dicotyledonous hardwood features. The juvenile wood and unidentified organic tissue might be derived from the same taxa as the identified types. As a result, the assemblage is composed of at least 30 different taxa.

Charcoal type distribution pattern

The distribution of the charcoal types reveals no clear stratification, as most types are present throughout the profile (Fig. 4). However, some types are confined to the upper intervals (0–10 to 50–60 cm; CAE CYN SES, ANN NEO GAB, PAP CAM SCA, all unidentified monocotyledons) and some are confined to the lower intervals (APO ALS SPP, MYR PYC ANG). Furthermore, constrained cluster analysis yields six significantly different depth zones, and unconstrained cluster analysis reveals five significantly different interval groups (Fig. 5; Birks and Gordon 1985; Bennett 1996; Juggins 2012). The constrained cluster analysis dendrogram shows that the

Lukula profile

soil type: Gb3m

5° 26´ 6.96´´ S

12° 57´ 41.7´´ E

Depth [cm]	Age [cal yr BP] (2σ)	# charcoal fragments	# studied fragments	# studied charcoal fragments per charcoal type (m)																															
				CAE CYN SES	ANN NEO GAB	IRV IRV GAB	CHR PAR SPP	PAN MIC SPP	ANA PSE MIC	CAE APH SPP	CLU MAM AFR	MOR FIC SPP	PAS PAR GRE	SAP CHR SPP	SAP PAN SPP	CAE BER SPP	ANN XYL AET	EUP MAR MIC	PAP CAM SCA	MOR MIL EXC	APO ALS SPP	BUR CAN SCH	MOR MUS CEC	MYR PYC ANG	oil palm endocarp	MYR RAP MEL	PHY BRI FER	APO VOA SPP	PAP MIL SPP	monocot	monocot	monocot	mature wood	juvenile wood	unidentified tissue
0-10	-	>200	51													1			9				1		5	13				3	7	4		5	3
10-20	-	>200	51						10														1		24	3					2	6		2	3
20-30	900 - 685	>200	51	3	5	5			1	2		4	2			1							2		20	1	1			2			1	1	
30-40	-	>200	51				1	1		4	1			2		5				3		2			18		4	7	2					1	
40-50	2304 - 2000	>200	51			5	2	2		4	1					2	1	1		6		1			10	1	10	5							
50-60	-	>200	51				1	4	7	1	1	4	4	1	1	5	1					2	3		11	1	2	2							
60-70	-	>200	51					8	3	9		1		1	4	2				3	1				10		2		7						
70-80	-	>200	51					1	1		13	2	1		2		1					1	1	6	20	1	1								
80-90	-	>200	51							7	3	7	3							1		1	6		20		2							1	
90-100	966 - 810	>200	51						1	11	6	2	2	9	2					1		4	3		6		1		3						
100-110	1170 - 969	37	37							5							2				1	4			23								1	1	
110-130	-	24	24								2							3			4				9		1	3	1						1
130-140	-	15	15							1			2				1	2			1		1		4								1	1	1
140-160	-	0	0																																

(a) ecology of the highest ranked woody species:

- mature rainforest species
- regenerating rainforest species
- pioneer species
- woodland savanna / open vegetation types / large ecological tolerance

Fig. 4 Distribution of charcoal types throughout the profile. *Grey shades* reflect the phytosociological classification of the highest ranked taxa for each charcoal type

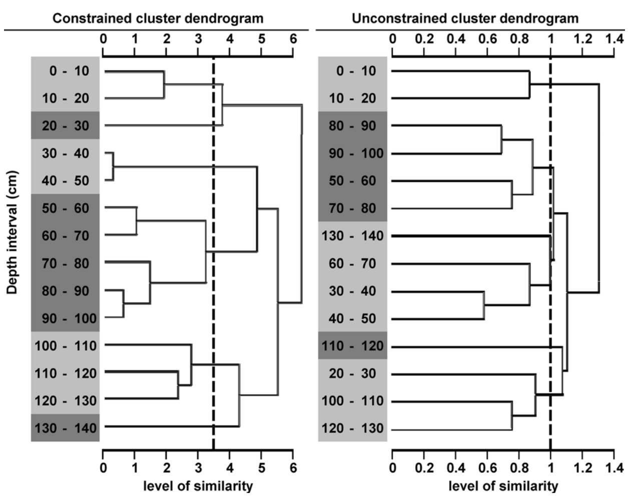

Fig. 5 Constrained and unconstrained cluster dendrograms for the charcoal type distribution pattern presented in Fig. 4. *Grey shades* demarcate statistically different depth interval groups at the level of similarity indicated by the *dotted line*

charcoal assemblages in the 30–50 cm depth intervals are more similar to those in the 50–100 cm intervals than the assemblages in the 0–30 cm intervals, at the 5th level of similarity. In the unconstrained cluster analysis dendrogram, the 20–30 cm depth interval joins the 110–130 cm intervals, and the 30–50 cm intervals join the 60–70 cm and the 130–140 cm intervals (Fig. 5). As such, we can conclude that the distribution pattern of charcoal types is not stratified. The charcoal fragments from the 0–50 cm intervals do not form a coherent group as opposed to those from the lower intervals.

Identification reliability

For each of the 25 identified charcoal types, Table 1 presents the highest anatomical rank, the number of highest ranked taxa and the vegetation types in which the highest ranked taxa occur, together with identification reliability based on two criteria (see also Hubau et al. 2013). For nine charcoal types, only one taxon was ranked highest after identification, which excludes any possible confusion regarding the habitat preference of the taxon from which the charcoal originates (ANA PSE MIC, CLU MAM AFR, MOR MUS CEC). For the other types, several taxa were ranked highest, with a maximum of six (MOR FIC SPP). In some cases, the highest ranked taxa have different phytosociological characteristics, which impede palaeoecological interpretation of the charcoal type. If this is the case, the charcoal type gets a negative (−) score for evaluation criterion a. Evaluation criterion b specifies how well the highest ranked taxa resemble the charcoal type. Based on both criteria, an identification reliability rank is assigned to each charcoal type.

Identification is very reliable for 80 % of all charcoal types (ranks 1 or 2), because their highest ranked taxa do not have ambiguous phytosociological characteristics and resemble the charcoal type anatomy almost perfectly or at least very well (Table 1). None of the types have highest ranked taxa that resemble the charcoal anatomy only moderately (ranks 3 or 6). Only 20 % (five types) of all identified charcoal types are not reliable (ranks 4 or 5) because their highest ranked taxa occur in different forest types. This complicates the assignment of these types to a single phytosociological community, such as mature rainforest, pioneer forest etc. An example is charcoal type APO VOA SPP, for which five woody taxa, resembling the charcoal anatomy almost perfectly, were ranked highest. Phytosociological characteristics of these species are ambiguous. *Voacanga africana*, *V. chalotiana* and *V. thouarsii* occur in secondary forest and in woodland savanna, whereas *Tabernaemontana brachyantha* occurs in mature evergreen or semi-deciduous rainforest and in gallery forest, and *T. africana* occurs especially in woodland savanna (Lebrun and Gilbert 1954; Burkill 1985; Protabase 2012, see also Table 1). As such, charcoal type APO VOA SPP cannot be assigned to a single vegetation type.

Firewood characteristics and preference

Firewood characteristics were quantified for 15 charcoal types whose highest ranked taxa resemble the charcoal anatomy almost perfectly (Table 2). To do so, for each of these charcoal types a representative species (preceded by 'cf.' in Table 2) was chosen from the list of highest ranked species (Table 1), depending on the availability of wood specimens in the reference collection of the RMCA. No distinction was made between large trees, small trees or shrubs. Wood density ranges between 111 and 838 kg m^{-3}. HHV ranges between 18.52 and 20.33 MJ kg^{-1}, taking into account standard errors.

Preferred woody taxa for current charcoal production are presented in ESM 1, along with Kiyombe names as reported by inhabitants of five different villages in the neighbourhood of the Lukula community. Only 6 of the 71 reported species are amongst the highest ranked species of one of the 30 ancient charcoal types: *Canarium schweinfurthii*, *Irvingia grandifolia*, *Mammea africana*, *Milletia versicolor*, *Musanga cecropioides* and *Pseudospondias microcarpa* (indicated in dark grey in ESM 1).

Discussion

Archaeological context of the Lukula deposits

On the whole, archaeological evidence is scarce for the Republic of Congo and the DRC. The Lukula profile analysed in the present study is the only site providing evidence of the presence of ironworkers in the Bas-Congo region around 1,000 cal. B.P., though it is known that iron smelting was practised at the Sakusi site (DRC) as early as 1,950–1,600 cal. B.P. (Fig. 1; De Maret 1972; Gosselain 1988; Kanimba Misago 1991; Clist 1982, 2005), while in the RoC it was known earlier still, before 2,000 cal. B.P. (Denbow 1990, 2012; Schwartz et al. 1990; De Foresta 1990; Dupre and Pinçon 1997). The presence of iron slag fragments and scattered pot sherds indicates that the profile was located at or near an old settlement. The profile was situated on a flat hillcrest that could have been a preferred settlement position like the one chosen at least 400 years earlier for the Kay Ladio community at the Sakusi site, located less than 200 km east of Lukula (Fig. 1; De Maret 1972; Gosselain 1988; Kanimba Misago 1991; Clist 2005).

The presence of two apparently separated artefact assemblages, as well as the distinct age gap between two groups of radiocarbon dates could be seen as an indication that the profile represents two charcoal and artefact assemblages. However, the calibrated dates are too close to suggest that they are the result of two separate occupation periods on the hilltop. Also, the profile is heavily affected by bioturbation. Moreover, the lack of a significant charcoal-free interval and the lack of a stratified distribution pattern of charcoal types over the entire profile depth suggests that the assemblage is a result of continuous deposition rather than two or more separate 'throw away' events. Radiocarbon dates suggest that the assemblage has been formed over a period of more than 400 years, between 1,143 and 717 cal. B.P. (Fig. 3).

Only two pottery sherds of the Lukula assemblage provide some information on the form and decoration of the pots. An undecorated carinated (keeled) fragment found at 90–100 cm depth shows part of the pottery body and shoulder. Secondly, a decorated sherd was found at 40–50 cm depth. This suffices to conclude that the pottery style differs from that of the older traditions such as Ngovo and Kay Ladio in the Bas-Congo region (De Maret 1972; Gosselain 1988; Kanimba Misago 1991; Clist 2005) or the Tchissanga ware in the RoC (Denbow 1990, 2012). The decorated sherd from the upper levels could be either early or late Iron Age, but carinated profiles only occur in later traditions in the RoC (Denbow 2012) or DRC assemblages from Bas-Congo (De Maret 1972; Clist 1982, 2012) or from Bandundu (Fig. 1; Pierot 1987). Further excavations will be needed to understand the archaeological significance of the Lukula assemblage, but the data available agrees well with the general archaeological sequence of the area.

Reconstructed vegetation types

Mature rainforest was an important constituent of the environment around Lukula between 1,200 and 700 cal. B.P. as indicated by 12 out of 26 identified types in the studied profile (Table 1; Fig. 4). The most prominent indicators of mature evergreen and semi-deciduous rainforest are amongst the highest ranked taxa of charcoal types ANA PSE MIC (cf. *P. microcarpa*), CLU MAM AFR (cf. *M. africana*), CAE CYN SPP (cf. *Cynometra* sp.) and CAE APH SPP (cf. *Aphanocalyx* sp.) (Table 1; Lebrun and Gilbert 1954; Burkill 1985; Leal 2004; African Plants

Table 2 Representative species and firewood quality data for each charcoal type which resembles wood anatomy of one or more species almost perfectly (anatomy rank 5)

Charcoal type	Family	Representative species	Morphology	Position in tree	Oven-dry density (kg m^{-3})	HHV (MJ kg^{-1})
ANA PSE MIC	Anacardiaceae	cf. *Pseudospondias microcarpa* (A. Rich.) Engl.	Small tree or shrub	Stem	476	18.89 ± 0.37
APO ALS SPP	Apocynaceae	cf. *Alstonia boonei* De Wild.	Large tree	Small stem	274	19.62 ± 0.37
BUR CAN SCH	Burseraceae	cf. *Canarium schweinfurthii* Engl.	Large tree	Stem	485	19.05 ± 0.11
CLU MAM AFR	Clusiaceae	cf. *Mammea africana* Sabine	Large tree	Stem	705	19.93 ± 0.05
EUP MAR MIC	Euphorbiaceae	cf. *Mareya micrantha* (Benth.) Müll. Arg.	Small tree or shrub	Small branch	657	19.63 ± 0.32
MOR MIL EXC	Moraceae	cf. *Milicia excelsa* (Welw.) C.C. Berg	Large tree	Stem	624	20.01 ± 0.33
MOR MUS CEC	Moraceae	cf. *Musanga cecropioides* R. Br. ex Tedlie	Large tree	Stem	111	19.27
MOR MUS CEC	Moraceae	cf. *Musanga cecropioides* R. Br. ex Tedlie	Large tree	Branch	440	19.41 ± 0.03
MOR MUS CEC	Moraceae	cf. *Musanga cecropioides* R. Br. ex Tedlie	Large tree	Stilt root	482	20.25
PAS PAR GRE	Passifloraceae	cf. *Paropsia grewioides* Welw. ex Mast.	Shrub	Small stem	726	19.23 ± 0.08
IRV IRV GAB	Irvingiaceae	cf. *Irvingia gabonensis* (Aubry-Lecomte ex O'Rorke) Baill.	Large tree	Stem	780	19.64 ± 0.66
MYR PYC ANG	Myristicaceae	cf. *Pycnanthus angolensis* (Welw.) Exell	Large or small tree	Small stem	369	19.16 ± 0.06
PAN MIC SPP	Pandanaceae	cf. *Microdesmis kasaiensis* J. Léonard	Shrub	Stem	691	19.36 ± 0.39
SAP PAN SPP	Sapindaceae	cf. *Pancovia harmsiana* Gilg	Small tree or shrub	Stem	693	19.22 ± 0.15
APO VOA SPP	Apocynaceae	cf. *Voacanga thouarsii* Roem. & Schult.	Small tree or shrub	Stem	474	19.30 ± 0.03
CAE CYN SES	Caesalpinioideae	cf. *Cynometra sessiliflora* Harms	Small tree	Stem	838	19.08 ± 0.11
CHR PAR SPP	Chrysobalanaceae	cf. *Parinari curatellifolia* Planch. ex Benth.	Large tree	Stem	597	19.26 ± 0.16

Database 2012). Also, the highest ranked taxa of charcoal types ANN NEO GAB, PAS PAR GRE, SAP CHR SPP and IRV IRV GAB typically occur in mature rainforest environments.

Ten out of 26 identified charcoal types are most probably derived from short-lived or long-lived pioneer taxa (Table 1; Fig. 4). The highest ranked taxa of types MOR MUS CEC (cf. *M. cecropioides*), MYR PYC ANG (cf. *Pycnanthus angolensis*) and *E. guineensis* are among the most typical and widespread pioneers of the Central African rainforest, regenerating very well after forest disturbance (Lebrun and Gilbert 1954; Burkill 1985; African Plants Database 2012; Protabase 2012). Also, the highest ranked taxa for charcoal type APO ALS SPP (cf. *Alstonia boonei*) are typical light-demanding indicator taxa in regenerating forest, although seedlings tolerate some shade (Protabase 2012). The highest ranked taxa for charcoal type PAP CAM SCA (cf. *Camoensia scandens*) are lianas typically occurring in regenerating forest and regenerating savanna, forest edges and in gallery forest. The highest ranked taxa for charcoal types EUP MAR MIC (cf. *Mareya micrantha*), ANN XYL AET (cf. *Xylopia aethiopica*), BUR CAN SCH (cf. *C. schweinfurthii*) and MOR MIL EXC (cf. *M. excelsa*) are long-lived pioneers which can persist in mature rainforest, gallery forest and forest islands or as relicts in savanna and farmland.

Four types are not clearly identified as mature or regenerating rainforest taxa. A reliable identification is that of type PHY BRI FER (Table 1). The highest ranked taxa (cf. *Bridelia ferruginea*) are typical light-demanding trees or shrubs occurring in open forest or woodland savanna with seasonally variable climate conditions, although they also occur at mature rainforest edges (Lebrun and Gilbert 1954; Burkill 1985; African Plants Database 2012). Vincens et al. (1998) explicitly mention *B. ferruginea* as a typical element of the Niari grasslands lying in the rain shadow of the Mayumbe hills. All *Millettia* species ranked highest for charcoal type PAP MIL SPP have a large ecological amplitude, ranging from mature semi-deciduous rainforest to old secondary forest, gallery forest, forest edges and woodland savanna (Burkill 1985; African Plants Database 2012; Protabase 2012). Identification of charcoal type APO VOA SPP is ambiguous. Finally, identification of charcoal type MYR RAP MEL is somewhat surprising. *Rapanea melanophloeos* is the only highest ranked species, although it is a typical shrub (0–5 m) or small tree (5–20 m) occurring in sclerophilous mountainous and submountainous open forest and thickets (Lebrun and Gilbert 1954; Burkill 1985; Protabase 2012). Perhaps this result could be explained by the fact that the identification protocol does not cover all Central African species (cf. Hubau et al. 2012).

The presence of mature rainforest taxa, pioneers, secondary forest taxa, woodland savanna taxa and taxa with a large ecological tolerance indicates that no particular forest type was preferred for firewood gathering. This is in agreement with modern species preferences. Seven of the 71 species currently used for charcoal production (ESM 1) are typical indicators of semi-deciduous rainforest (Lebrun and Gilbert 1954), from which three belong to the top ten in some villages (such as *Pteleopsis hylodendron*). Furthermore, 12 taxa in the same list are typical indicators of secondary forest, and two species are indicators of woodland savanna.

Firewood preferences

The principle of least effort versus intentional gathering

Some authors assume that no species preference exists and postulate that firewood is gathered rather randomly, whereby wood characteristics or possible traditional values are subordinate to the ease of gathering. This lack of a specific selection strategy is known as the 'Principle of Least Effort' (Schwartz et al. 1990) which states that selection criteria are not important in regions where firewood is scarce, whereas non-species related properties such as moisture content, proportions and physiological state are the most important selection criteria in regions where firewood is abundant (Shackleton and Prins 1992; Théry-Parisot et al. 2010; Picornell-Gelabert et al. 2011). The Lukula assemblage, containing 30 charcoal types (Fig. 4), illustrates that many taxa were used, regardless of their habitat, which suggests that no species selection strategies were applied when gathering firewood.

On the other hand, the slightly differing radiocarbon dates suggest that the assemblage was formed over a certain time span (Fig. 3), which contrasts with the lack of vertical variation in charcoal type distribution (Figs. 4, 5). This could be due to repeated use of a limited set of intentionally gathered species. This 'societal filter' always has to be considered when interpreting archaeobotanical results (Théry-Parisot et al. 2010). Earlier studies have shown the absence of any relationship between species abundance in the environment and frequency of their use as firewood in present-day local communities, indicating that species selection is a function of intrinsic wood qualities (Ramos et al. 2008b). This is confirmed by positive relationships between current firewood preferences and firewood quality criteria such as density, water content, calorific value, wood density, ash content and water content (Ramos et al. 2008a). Also, southern African respondents identified a fast drying rate, production of long-lasting embers, low weight and low moisture content as decisive selection criteria (Abbot et al. 1997). But can these firewood quality criteria explain the composition of the Lukula assemblage?

Wood density

Wood density and moisture content in air-dry condition are decisive factors for firewood preference in South African savanna communities (Davis and Eberhard 1991; Abbot et al. 1997). However, measured oven-dry density values for representative species of the types in the Lukula assemblage are highly variable, ranging from 111 to 838 kg m^{-3} (Table 2). Worldwide, the heaviest woods have oven-dry densities of up to 1,200 kg m^{-3} (*Diospyros* spp.) (Dahms 1999). This implies that the density range of the taxa recognized in the Lukula profile (Table 2) already covers a large part of the possible range, indicating that there was no preference for particular heavy or light woods.

Very light woods burn fast, but they can be used to quickly start a fire. Moreover, they are easy to transport. Examples from the Lukula types are MOR MUS CEC (cf. *M. cecropioides*), APO ALS SPP (cf. *A. boonei*) and MYR PYC ANG (cf. *P. angolensis*) (Table 2). On the other hand, heavy woods are preferred for their production of long-lasting embers and high heat production, which are favourable characteristics for cooking and iron smelting (Abbot et al. 1997; Munalula and Meincken 2008). Examples from the studied charcoal types are CAE CYN SES (cf. *C. sessiliflora*), IRV IRV GAB (cf. *I. gabonensis*) and PAS PAR GRE (cf. *Paropsia grewioides*). This indicates that preferences regarding density are a function of very particular activity-related requirements.

Calorific value

Measurements of calorific value of 111 tropical hardwood species from Africa, South America and Asia, yielded an average HHV of 19.96 MJ kg^{-1} with maximum values of >21.7 MJ kg^{-1} and minimum values of <18.4 MJ kg^{-1} (Doat 1977). Considering the results of this survey, calorific values of the taxa selected by the Lukula community cover a broad range (18.52–20.33 MJ kg^{-1}, Table 2). Other studies confirm that calorific values do not vary much in tropical woods and are of minor importance for firewood selection by local communities (Abbot et al. 1997; Eberhard 1990). Although a high calorific value could be favoured for its energy efficiency and for its potential to allow the reaching of high temperatures for activities such as iron smelting and pottery firing (Livingstone-Smith 2001; Braadbaart and Poole 2008), it is also correlated with high extractive concentrations (Doat 1977; Kataki and Konwer 2001) which may cause poisonous smoke. Woods producing toxic smoke are unfavourable for household purposes (Munalula and Meincken 2008), but this might not be a decisive factor in firewood selection for practices such as iron smelting.

Religious, magical, medicinal and other values

The idea of an intentional firewood selection strategy for iron smelting has been succinctly discussed in a study of iron smelting sites in the Teke highlands, RoC (Fig. 1; Pinçon 1990). In three early Iron Age slag heaps dated around 1,800 cal. B.P., the scarcity of taxa in the charcoal assemblage could reflect a true selection strategy. However, only 20 fragments were identified per heap and most selected taxa were probably totally consumed during the smelting process, as indicated by the small concentration of charcoal there (Pinçon 1990). The few charcoal fragments that were found probably belonged to the wood that was added at the end of the smelting process, when magical and religious criteria were more important than a high calorific value. Specifically, most of the identified fragments belonged to Apocynaceae, which are believed to have magical virtues but which do not have particularly high calorific values compared to high-quality firewood.

Likewise, the Lukula assemblage contains two charcoal types derived from Apocynaceae: APO ALS SPP (cf. *Alstonia* spp.) and APO VOA SPP (cf. *Voacanga* spp.), yielding widely appreciated latex and poison (Fig. 4; Table 1) (Koni Muluwa 2010). Also, some of the highest ranked taxa of charcoal types BUR CAN SCH (cf. *C. schweinfurthii*), PAN MIC SPP (cf. *Microdesmis puberula*) and MOR MUS CEC (cf. *M. cecropioides*) play an important role in ceremonial traditions and local medicine (Burkill 1985; Latham 2004; Koni Muluwa 2010; Protabase 2012).

Ancient versus modern preferences

Only 6 of the highest ranked taxa were among the 71 species reported as being preferred for charcoal production in the southern Mayumbe (ESM 1) and only one of these six taxa (*M. versicolor*; type PAP MIL SPP) was reported within the top ten of preferred species in one of the present-day villages. The most important species today are *Celtis mildbraedii*, *Hylodendron gabunense* and *P. hylodendron*, and they are nowadays preferred above all others, even though they may be hard to find, because they are easy to cut, produce a lot of charcoal and their charcoal burns slowly, according to the respondents. Yet these species were not found in the Lukula profile. As such, the question arises why the overlap between ancient and present-day preferences is so minimal.

One possible explanation is that preferences change over time. Some of the taxa reported by the respondents and/or ranked after identification have names in Kiyombe that are not widespread among western Bantu languages, such as *A. boonei* (*tsóóngútí*, De Grauwe 2009), *P. microcarpa* (*nzuúza*, ESM 1) and *C. mildbraedii* (*néemba*, ESM 1), and they are probably of fairly recent origin. As such, the linguistic evidence does not indicate that Bantu speakers knew these taxa before their arrival in the Bas-Congo although some of them, such as *C. mildbraedii* are among the most preferred species today (ESM 1).

However, some of the reported Kiyombe names are very old (ESM 1; Raponda-Walker and Sillans 1995; Bostoen 2013; Bostoen et al. 2013; Koni Muluwa 2010). The most prominent example is *E. guineensis* (oil palm) which has always played a very important role in food preparation in Central Africa and whose charred endocarps are commonly abundant in archaeological excavations such as the Lukula profile (Fig. 2; Dechamps et al. 1992; Maley and Chepstow-Lusty 2001). In Kiyombe, it is known as *dííba* (De Grauwe 2009), a name which is widespread among western Bantu languages (Bostoen 2005, 2013; Bostoen et al. 2013). Furthermore, the pioneer species *M. cecropioides* (type MOR MUS CEC) is known as *nsééngá*, *C. schweinfurthii* (BUR CAN SCH) as *mbíídí*, *X. aethiopica* (ANN XYL AET) as *múkhaala*, *M. africana* (CLU MAM AFR) as *mbooza* and *P. angolensis* (MYR PYC ANG) as *lomba* (ESM 1; De Grauwe 2009; SPIAF 1988). Bantu speakers knew these trees before they started to settle in the Bas-Congo area. Their Bantu names are certainly older than the charcoal remains found in the Lukula profile and dated 1,200–700 cal. B.P.

Consequently, the linguistic evidence points towards a long exploitation history for some of the recorded taxa but not for all of them. This indicates that selection strategies were not always maintained over time. Also, selection strategies may have been very different depending on the activity. The respondents reported only species used for charcoal production whereas one could expect that the settlement of an iron smelting community would contain refuse from a wide variety of activities, such as cooking, heating, iron smelting, pottery production or fuel burning for ceremonial or medicinal purposes. This is in line with the wide variety of taxa in the Lukula assemblage and the wide variety in species characteristics such as morphology, phytosociological characteristics, wood density, calorific value and traditional virtues (Tables 1, 2). This confirms the fact that the notion of a 'good fuel' has to be considered within the framework of specific uses (Théry-Parisot et al. 2010). In fact, there is not one good fuel but a wide choice of adaptable fuels that can be more or less convenient for a wide range of different activities.

Palaeoclimatic context

No prevalent species-related qualitative firewood characteristics are recognized in the Lukula charcoal assemblage. Moreover, it is possible that the assemblage formed over a relatively long period rather than during one specific event. This indicates that the Lukula assemblage is a 'synthetic' deposit of scattered charcoal fragments, resulting from long-term deposition. Taxon compositions of such deposits may predominantly reflect the surrounding environment (Théry-Parisot et al. 2010). Based on vegetation type reconstructions, one could assume that the environment around Lukula between 1,200 and 700 cal. B.P. was dominated by mature rainforest (Fig. 4). However, the assemblage also contained a significant number of pioneer and regenerating forest taxa (Fig. 4), indicating ongoing forest regeneration as a result of earlier disturbance. Moreover, phytosociological characteristics of the highest ranked taxa of charcoal types PHY BRI FER, PAP MIL SPP and APO VOA SPP indicate the proximity of open vegetation types (Lebrun and Gilbert 1954; Burkill 1985; Protabase 2012).

The Lukula community is currently located in a fragmented landscape that is dominated by mature rainforest to

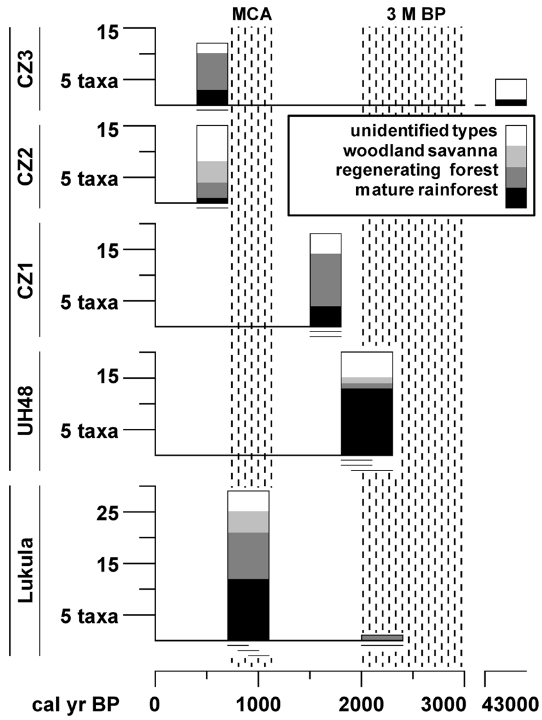

Fig. 6 The Lukula assemblage presented on a timeline, next to charcoal assemblages from profiles excavated in mature rainforest in the neighbouring Luki reserve. *Grey shades* reflect the phytosociological classification of the highest ranked species for each taxon. Dashed areas indicate palaeoclimatic disturbance periods (*3 M BP* 3rd millennium B.P rainforest crisis, *MCA* Medieval Climate Anomaly)

the north and by woodland savanna to the south (Fig. 1). This fragmented pattern is most probably a legacy of intense human activity during the last centuries. Yet, human impact on the forest before and around 1,000 cal. B.P. was probably less important (Brncic et al. 2007; Maley et al. 2012; Neumann et al. 2012b). Therefore, forest disturbance and fragmentation between 1,200 and 700 cal. B.P., as recorded by the presence of pioneer taxa in the Lukula profile, may have been a result of a climatic anomaly.

Figure 6 presents the Lukula charcoal assemblage next to charcoal assemblages found in non-archaeological soil profiles situated in mature rainforest in the Luki reserve (Hubau et al. 2013). The assemblages of profiles CZ1, CZ2 and CZ3 show a dominance of regenerating forest and woodland savanna taxa. These reconstructions have been interpreted as an indication of regeneration after natural forest fragmentation caused by drought anomalies (Hubau et al. 2013). Specifically the CZ2 and CZ3 assemblages reflect fragmentation and regeneration after the Medieval Climate Anomaly (MCA) and the CZ1 assemblage was formed after the third millennium rainforest crisis (Maley and Brenac 1998; Ngomanda et al. 2009a, b). Likewise, the presence of pioneer taxa and ones typical of open vegetation types in the Lukula assemblage (Figs. 4, 6) could reflect forest fragmentation as a result of a climatic anomaly associated with the MCA, which was undoubtedly a period of rapid climate change (Russell and Johnson 2007; Verschuren and Charman 2008). Evidence from pollen analysis indicates that the MCA significantly disturbed the Lower Guinean rainforest, especially at the forest margins where the Lukula profile is situated (Fig. 1). Specifically, a decrease in mature rainforest taxa and an increase in shade-intolerant taxa were reported in Gabon (Ngomanda et al. 2007). Similarly, in northern RoC, forests dominated by shade-bearers were abruptly replaced by herbs and light demanders between 1,345 and 900 cal. B.P. (Brncic et al. 2009).

Conclusion

An archaeological assemblage near the Lukula community located at the southernmost boundary of the Mayumbe forest, Bas-Congo, DRC, yielded pot sherds, iron slag and charcoal resulting from human activities covering a period between 1,200 and 700 cal. B.P. Analysis of charcoal fragments yielded 30 different charcoal types of which 26 were identified; 12 types were derived from mature rainforest taxa, ten from prominent pioneer or regenerating forest taxa and four from woodland savanna taxa or taxa with a large ecological tolerance. A list of 71 taxa preferred for modern charcoal production in the southern Mayumbe shows the same ecological variety. This indicates that ancient and current communities gathered firewood in several different forest types.

Wood density ranges from 111 to 838 kg m^{-3} and HHV ranges between 18.52 and 20.33 MJ kg^{-1}. These are very broad ranges, indicating that no woods with specific densities or calorific values were preferred. As such, no particular wood qualities determine the Lukula assemblage, although some taxa might have been selected for their magical or medicinal values.

Modern firewood preferences differ from ancient preferences and linguistic evidence points towards a long exploitation history for some of the recorded taxa in the Lukula assemblage, but not for all of them. This suggests that selection strategies were not always maintained. Also, selection strategies might be very different depending on the activity. The settlement of this ancient community probably contained remains from a wide variety of activities such as cooking, heating, iron smelting, pottery production and fuel burning for ceremonial or medicinal purposes and indicates that perceived firewood quality depends on activity-specific requirements.

As there seems to be a lack of species preferences, the charcoal assemblage is representative of the composition of the vegetation surrounding the Lukula community between 1,200 and 700 cal. B.P. The presence of different vegetation types suggests a rather fragmented landscape. In contrast to current forest-savanna mosaics, fragmentation around 1,000 cal. B.P. cannot be explained exclusively by human activity. Fragmentation may have been partly caused by a climatic event coinciding with the MCA, as evidence for its impact on palaeoclimatic conditions in Central Africa is increasing.

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