

Archaeological Evidence for Population Rise and Collapse between ~2500 and ~1500 cal yr BP in Western Central Africa

Geoffroy de Saulieu, Yannick Garcin, David Sebag, Pascal R. Nlend Nlend, David Zeitlyn, Pierre Deschamps, Guillemette Ménot, Pierpaolo Di Carlo, Richard Oslisly

**Geoffroy de Saulieu** [geoffroy.desaulieu@ird.fr](mailto:geoffroy.desaulieu@ird.fr) – Patrimoines Locaux Environnement et Globalisation UMR 208, IRD, MNHN, 57 rue Cuvier - Case Postale 51, 75231 Paris cedex 05 (France)

**Yannick Garcin** [garcin@cerege.fr](mailto:garcin@cerege.fr) – Aix Marseille Université, CNRS, IRD, INRAE, Collège de France, CEREGE, Aix-en-Provence (France)

**David Sebag** [davidsebag.ird@gmail.com](mailto:davidsebag.ird@gmail.com) – Normandie Université, UNIROUEN, UNICAEN, CNRS, M2C, 76000 Rouen, (France)/Institute of Earth Surface Dynamics, Geopolis, Université de Lausanne, Lausanne, (Switzerland)/HSM, IRD, CNRS, Université de Montpellier, Montpellier (France)

**Pascal R. Nlend Nlend** [pr\\_nlend@yahoo.fr](mailto:pr_nlend@yahoo.fr) – Université de Yaoundé I, Département des Arts et de l'Archéologie et Centre de Recherche et d'Expertise scientifique, Yaoundé (Cameroun)

**David Zeitlyn** [david.zeitlyn@anthro.ox.ac.uk](mailto:david.zeitlyn@anthro.ox.ac.uk) – Institute of Social and Cultural Anthropology, School of Anthropology and Museum Ethnography, University of Oxford (UK)

**Pierre Deschamps** [deschamps@cerege.fr](mailto:deschamps@cerege.fr) – Aix Marseille Université, CNRS, IRD, INRAE, Collège de France, CEREGE, Aix-en-Provence (France)

**Guillemette Ménot** [guillemette.menot@ens-lyon.fr](mailto:guillemette.menot@ens-lyon.fr) – ENSL, Université de Lyon 1, CNRS, LGL-TPE, F-69007 Lyon (France)

**Pierpaolo Di Carlo** [pierpaolodicarlo@gmail.com](mailto:pierpaolodicarlo@gmail.com) – Department of Linguistics, University at Buffalo, The State University of New York (USA)

**Richard Oslisly** [roslisly@parcsgabon.ga](mailto:roslisly@parcsgabon.ga) – Cellule Scientifique, Agence Nationale des Parcs Nationaux, BP 20379 Libreville (Gabon)/Patrimoines Locaux Environnement et Globalisation UMR 208, IRD, MNHN, 57 rue Cuvier, case postale 51, 75231 Paris cedex 05 (France)

## Abstract

Palaeocological studies show that major vegetation and environmental changes occurred in Central Africa from the mid-Holocene (e.g. Maley & Brenac 1998). Several suggest a human origin and assume that large population migration, technical innovations (e.g., iron-smelting technology) and/or change in agricultural practice, leading to deforestation and land clearance, are the drivers of these changes. However, at this stage, the lack of demographic reconstruction does not fully support such these hypotheses. Here, a georeferenced archaeological database is used to infer population dynamics and the evolution of cultural

practices in Western Central Africa over the last 5000 years. This database includes 1139 <sup>14</sup>C calibrated dates from 425 sites located throughout southern Cameroon, Gabon, the Republic of Congo, Equatorial Guinea and the western part of the Democratic Republic of Congo, dating back a maximum of 5000 cal years BP. Data modelling indicate possible population growth from 2500 to 1500 calendar years before AD 1950 (cal. y BP), coinciding with the occurrence at a regional scale of specific techniques and practices. The concomitant increase of refuse pits, palm oil *Elaeis guineensis* and iron metallurgy (plus rare remains of millet *Pennisetum glaucum*) took place during the second half of the Neolithic, beginning around 2800 cal yr BP. In the coastal regions, the population growth concerns the Neolithic and the Early Iron Age (2500-2000 cal yr BP and 2000-1500 cal yr BP), while in the Hinterland population growth seems slightly later (2400 and 1300 cal yr BP). It is not possible to identify a common diffusion phenomenon from a single homeland. Rather, technical innovations and new practices appear to have spread through a wide network of cultural interactions, which fostered the formation of Western Central African societies during the third millennium.

**Keywords:** Western Central Africa, Cameroon, Gabon, Congo, Congo D. R., Equatorial Guinea, Late Holocene, Archaeology, prehistoric demography, spatial analysis, radiocarbon dating

## Résumé

« Preuve archéologique de l'augmentation et de l'effondrement de la population entre ~2500 et ~1500 ans cal. BP en Afrique centrale occidentale. ». Des études paléoenvironnementales antérieures ont montré que des changements majeurs de la végétation et de l'environnement se sont produits en Afrique centrale à partir de l'Holocène moyen (ex. Maley & Brenac 1998). Plusieurs d'entre elles mettent en évidence une origine humaine et supposent que les grandes migrations de population, les innovations techniques (par exemple, la technologie de la fonte du fer) et/ou de nouveaux choix dans les pratiques agricoles, conduisant à la déforestation et au défrichement, sont les moteurs de ces **changements**. Cependant, à ce stade, l'absence de reconstitution démographique ne permet pas de soutenir pleinement ces hypothèses. Notre étude utilise une base de données archéologiques géoréférencées pour déduire la dynamique des populations et l'évolution des pratiques culturelles en Afrique centrale occidentale au cours des 5000 dernières années. Cette base de données comprend 1139 dates calibrées au <sup>14</sup>C provenant de 425 sites – localisés dans le sud du Cameroun, au Gabon, en République du Congo, en Guinée équatoriale et dans la partie occidentale de la République démocratique du

Congo –, remontant à un maximum de 5000 ans cal. BP. La modélisation des données indique une possible croissance de la population entre ~2500 et ~1500 ans cal. BP, coïncidant avec l'apparition à l'échelle régionale de techniques et de pratiques spécifiques. L'augmentation concomitante des fosses dépotoirs, des vestiges d'utilisation de palmier à huile *Elaeis guineensis*, l'apparition des rares restes de millet *Pennisetum glaucum* et la montée en puissance des vestiges de métallurgie du fer ont eu lieu pendant la seconde moitié du Néolithique, à partir d'environ 2800 cal. BP. Dans les régions côtières, la croissance de la population concerne le Néolithique et le début de l'Age du Fer (2500-2000 cal BP et 2000-1500 cal BP), tandis que dans l'Hinterland cette croissance semble légèrement plus tardive (2400 et 1300 cal BP). Il n'est pas possible d'identifier un phénomène commun de diffusion à partir d'un seul centre. Les innovations techniques et les nouvelles pratiques semblent plutôt s'être répandues à travers un large réseau d'interactions culturelles qui a favorisé la formation des sociétés d'Afrique centrale occidentale au cours du troisième millénaire avant notre ère.

**Mots-clés :** Afrique centrale occidentale, Cameroun, Gabon, Congo, R. D. Congo, Guinée équatoriale, Holocene tardif, archéologie, démographie préhistorique, analyse spatiale, datation radiocarbone

### **Version abrégée en français**

*Preuve archéologique de l'augmentation et de l'effondrement de la population entre ~2500 et ~1500 ans cal. BP en Afrique centrale occidentale.*

Des études paléoenvironnementales antérieures ont montré que des changements majeurs de la végétation et de l'environnement se sont produits en Afrique centrale à partir de l'Holocène moyen (ex. Maley & Brenac 1998). Plusieurs d'entre elles mettent en évidence une origine humaine et supposent que les grandes migrations de population, les innovations techniques (par exemple, la technologie de la fonte du fer) et/ou le changement des pratiques agricoles, conduisant à la déforestation et au défrichement, sont les moteurs de ces changements (par ex. Bayon *et al.* 2012 et Garcin *et al.* 2018). Cependant, à ce stade, l'absence de reconstitution démographique à l'échelle régionale ne permet pas de soutenir pleinement ces hypothèses. Ici, une base de données archéologiques géoréférencées est utilisée pour déduire la dynamique des populations et l'évolution des pratiques culturelles en Afrique centrale occidentale au cours des 5000 dernières années (Fig. 1). Cette base de données comprend 1139 dates calibrées au  $^{14}\text{C}$  provenant de 425 sites localisés dans le sud du Cameroun, au Gabon, en

République du Congo, en Guinée équatoriale et dans la partie occidentale de la République démocratique du Congo. Afin de l'analyser, nous avons utilisé la méthode des *SPDs* (*Summed Probability Densities*) confrontée à des modèles statistiques reproduisant la croissance démographique et intégrant également les pertes taphonomiques. Cette approche a déjà été utilisée dans d'autres aires culturelles et pour d'autres périodes (par ex. Timpson *et al.* 2014 et Crema *et al.* 2016). Elle permet de reconstituer les périodes de croissance/décroissance démographiques relatives.

Les résultats indiquent une possible croissance de la population entre ~2500 et ~1500 cal. BP, coïncidant avec l'apparition à l'échelle régionale de techniques et de pratiques spécifiques (Fig. 2). L'augmentation concomitante des fosses dépotoirs, des vestiges d'utilisation de palmier à huile *Elaeis guineensis*, des rares restes de millet *Pennisetum glaucum* et de la métallurgie du fer, a eu lieu pendant la seconde moitié du Néolithique (Fig. 2A). Toutefois il n'est pas possible de mettre clairement en lumière l'existence d'un phénomène de diffusion initiale. En effet, les styles céramiques ne montrent pas de gradient d'antériorité permettant de constater l'existence d'un foyer d'origine (Fig. 3, 4). Pour vérifier cette première constatation, nous avons subdivisé de manière objective les sites archéologiques, sur la base de leurs coordonnées géographiques, en trois régions appelées « *North Coast* », « *Hinterland* » et « *South Coast* ». Nous avons ensuite réalisé séparément l'analyse des *SPDs* pour chacune (Fig. 5). Nous avons enfin procédé à une comparaison statistique régionale au moyen d'un « test de permutation ». Dans les deux régions côtières, la croissance de la population concerne le Néolithique et le début de l'Age du Fer (2500-2000 cal BP et 2000-1500 cal BP) ; tandis que dans la région « *Hinterland* » la croissance de la population semble légèrement plus tardive (2400 et 1300 cal yr BP) et ne présente pas les mêmes caractéristiques que dans les régions côtières (Fig. 6). Là non plus il n'est pas possible d'identifier un phénomène commun de diffusion à partir d'un centre. Les innovations techniques et les nouvelles pratiques semblent plutôt s'être répandues à travers un large réseau d'interactions culturelles, qui a favorisé la formation des sociétés d'Afrique centrale occidentale au cours du troisième millénaire avant le présent. Cela implique probablement la mise en place antérieure des populations des régions côtières à l'origine de la croissance démographique. La décroissance démographique constatée par la suite dans les trois régions reste d'autant plus énigmatique qu'elle est contemporaine des premiers intermariages entre les ancêtres des populations bantoues et pygmées actuelles, indiqués par les études génétiques (Patin *et al.* 2014, 2017).

## 1. INTRODUCTION

Through the development of rescue archaeology and the funding of international research programmes (e.g. Lavachery *et al.* 2010), archaeological research in Western Central Africa (henceforth WCA), comprising southern Cameroon, Gabon, the Republic of Congo, Equatorial Guinea, and the western part of the Democratic Republic of Congo, has made qualitative and quantitative progress since the 1990s. On the one hand, archaeology-only studies now include both site-specific analyses (e.g. Eggert & Seidensticker 2016) as well as regional syntheses (e.g. Bostoen *et al.* 2015; Bostoen 2018). On the other hand, there are a number of projects integrating archaeological data with palaeological (palaeoecological, palaeoclimatological, palaeoenvironmental), linguistic and genetic approaches (Quintana Murci *et al.* 2008; Berniell-Lee *et al.* 2009; de Filippo *et al.* 2012; Grollemund *et al.* 2015; Patin *et al.* 2017; Garcin *et al.* 2018; Lipson *et al.* 2020). The archaeological data accumulated in recent years cover several specific issues, including information on the first cultigens (palm oil, millet) (e.g. Neumann *et al.* 2012; Kahlheber *et al.* 2014), the evolution of regional cultures/ceramic styles (e.g. Wotzka 1995) and/or technological developments, such as the appearance, mastery and diffusion of iron metallurgy at a regional scale (e.g. Clist 2012).

Although the archaeological sites investigated are unequally distributed in WCA, the accumulated dataset of  $^{14}\text{C}$  dates associated with archaeological remains is now sufficient to infer regional population dynamics and to provide answers to specific questions regarding cultural dynamics (e.g., on ceramic styles, technology, etc.). Given the lack of human remains and ancient DNA in WCA, however, such an archaeological approaches cannot easily distinguish between the spatial dynamics necessarily involving the movement of people (migration, colonisation) and those without such a necessity (expansion/retreat of cultural styles, techniques and practices). Notwithstanding, through geochronological dating techniques (e.g.  $^{14}\text{C}$ ), archaeology can distinguish between various phenomena. First of all, there are centrifugal dynamics (of people, of practices or both) that, for convenience, will be called in this paper *diffusion*. For instance, the diffusion of the Neolithic culture in Europe is illustrated by a clear  $^{14}\text{C}$  age distribution indicating the movement of pioneer populations (Ammerman & Cavalli-Sforza 1971, 1979; Bocquet-Appel *et al.* 2009, Dubouloz 2017). At the regional scale, a time lag between various related occurrences arranged on a gradient in both time and space would strongly suggest diffusion of populations or cultural traits.

By contrast, a lack of spatial dynamics is more difficult to account for. Firstly, we cannot rule out that the methods available until now have been too imprecise to reveal any time lag. Secondly, it can also suggest that the modality of the cultural phenomenon in question is based on social interactions that are not yet understood. In this case, only local qualitative analyses may help to disentangle between diffusion and migration/colonisation processes (e.g. Eggert and Seidensticker 2016; Wotzka 1995).

Working from both demographic and cultural perspectives, this study compiles a regional dataset based on a comprehensive review of the archaeological literature concerning WCA during the last 5000 years. The review aims to (i) identify the key periods of regional population shifts through archaeological data, (ii) place the inferred population dynamics within a chronology of cultural and technical innovations and (iii) test the synchronicity of these innovations at a regional scale to show evidence of possible cultural diffusion processes. As a result, this study will provide an initial archaeological synthesis, independent of, but complementary to, current linguistic and genetic data, of a period of African prehistory in which the interplay between environmental changes, climate variability and human activities is still debated by scholars (Bayon *et al.* 2012; Clist *et al.* 2018; Garcin *et al.* 2018; Giresse *et al.* 2018; Maley *et al.* 2012; Neumann *et al.* 2012).

## **2. THE WESTERN CENTRAL AFRICAN ARCHAEOLOGICAL DATABASE AND STATISTICAL METHODS**

### **2.1. Radiocarbon ages and use**

This study uses a regional georeferenced database including 425 sites and 1139 published  $^{14}\text{C}$  dates from archaeological sites in WCA ranging between 5000 and 15  $^{14}\text{C}$  yr BP (Fig. 1). Compiled *Pennisetum glaucum*, *Elaeis guineensis*, iron metallurgy, and pit features, were either directly dated or we assumed that the age of a given material is equal to ages of nearby dated material. This body of work has already been partially published in a companion paper (Garcin *et al.* 2018) mainly focused on the respective roles of climate variability and human activity in the Late Holocene Forest crisis<sup>1</sup>. Radiocarbon dates and associated errors were

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<sup>1</sup> The ‘late Holocene rainforest crisis’ is a vegetation disturbance that is recorded in palaeoenvironmental proxies, mostly pollen, from several sites in Western Central Africa between 2800 and 2000 cal. yr BP (Ngomanda *et al.* 2009). It was originally described in the sediments of Lake Barombi in south-west Cameroon (Maley & Brenac 1998). Here, the crisis is recorded by a greater openness of the forest environment, an increase in the relative

rounded according to the convention proposed by Stuiver & Polach (1977).

The analysed samples straddle the Equator, extending from ~10°N to ~5°S, a zone which experiences seasonal variations in atmospheric CO<sub>2</sub>. Consequently, the <sup>14</sup>C calibration curve to apply can be either the InCal20 (Reimer *et al.* 2020) for the Northern Hemisphere, or the SHCal20 (Hogg *et al.* 2020) for the Southern Hemisphere, or a mix of both curves depending on the sample location. The distinction between the Northern and Southern Hemisphere atmospheres is not trivial and the boundary between them is set by the thermal Equator or the Intertropical Convergence Zone (ITCZ) at the time when the sample was formed (i.e., during the growing seasons in question), rather than by the geographic Equator (McCormac *et al.* 2004, Hogg *et al.* 2020). In the absence of any precise paleo-ITCZ reconstruction for the region, all dates were calibrated with SHCal20, based on the recommendation to use this curve for areas south of ITCZ in December-February (Hogg *et al.* 2020), which currently dominate WCA. The long-term hemispheric offset is  $36 \pm 27$  yr (SHCal10 minus IntCal20), which may create additional uncertainties in <sup>14</sup>C calibration (Hogg *et al.* 2020). Radiocarbon calibration and summed probability distributions (SPDs) were computed using the freely available R statistical computing package, Bchron 4.1.2 (Parnell 2015), and all ages are shown as calendar years before AD 1950 (cal y BP).

Before calculating the Summed probability distributions (SPDs) and other statistical analyses (see below), <sup>14</sup>C dates were binned to correct for investigator bias and oversampling within sites (Crema *et al.* 2016; Shennan *et al.* 2013; Timpson *et al.* 2014). To account for the highly variable sampling intensity across the study area, closely distanced radiocarbon dates were binned in space, using an arbitrary 10-km radius, with the ArcGIS 10.2.1 (ArcGIS, 2010) spatial analyst toolbox. Radiocarbon dates were further binned in time by clustering the mean <sup>14</sup>C yr using a threshold of 200 yr.

Human activity was inferred from the SPDs of <sup>14</sup>C-dated and/or associated material, including occurrences of *Pennisetum glaucum* (pearl millet), *Elaeis guineensis* (palm oil), iron metallurgy, and pit features. The age of any associated material was assumed to be the same as that of the nearby dated material.

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importance of *poaceae* and pioneer tree taxa, a relative decline in old-growth forest taxa, and an increase in pollen from the oil palm *Elaeis guineensis* – an heliophilic taxon commensal with humans.

## 2.2. Statistical Methods

Summed  $^{14}\text{C}$  dates (Fig. 1D) have often been used as a proxy for ancient demography, including Central Africa (Oslisly *et al.* 2013; Wotzka 2006), based on the idea that a larger amount of archaeological material and sites in an area reflects the presence of more people at the time (Oslisly *et al.* 2013). However, this method has evident weaknesses, mostly related to sampling bias, taphonomic loss and fluctuations in the radiocarbon calibration curve, such as that caused by the presence of a plateau (e.g., the Hallstatt plateau, Van der Plicht 2005), all of which reduce the reliability of demographic inference. To avoid the evident limitations of previous attempts and to produce a new and more credible representation of the region, we used recently developed demographic proxies based on the SPDs of calibrated  $^{14}\text{C}$  dates. This approach has been used in similar studies for Europe (Shennan *et al.* 2013; Timpson *et al.* 2014), Western Africa (Manning and Timpson 2014), South America (Goldberg *et al.* 2016; Riris & Arroyo-Kalin 2019), South West Asia (Roberts *et al.* 2018) and East Asia (Crema *et al.* 2016; Oh *et al.* 2017; Zahid *et al.* 2016). The method is now well established and was previously applied to Western Central Africa (Garcin *et al.* 2018). Seidensticker *et al.* (2021) recently used this method focusing on the post-1600 cal. yr BP period. In contrast, we focus here on the pre-1600 cal. yr BP period corresponding to the initial settlement history.

The usage of SPDs as a population proxy has been widely debated (see for example Contreras & Meadows 2014; Torfing 2015; Williams 2012; Lupo *et al.* 2018). If the shape of the SPDs is not overemphasized, this method provides valuable insight into palaeodemographic dynamics (Timpson *et al.* 2015; Crema & Bevan 2020).

Population dynamics were reconstructed from the SPDs of  $^{14}\text{C}$  dates compared with formal statistical models using the hypothesis-testing approach introduced in Shennan *et al.* (2013), further developed in Timpson *et al.* (2014) and provided in R (Team 2017), statistical computing language, by Crema *et al.* (2016). These analyses were recently implemented in an R package including more sophisticated features (Crema & Bevan 2021), however, we used the original code presented in Crema *et al.* (2016).

Here, the SPDs of  $^{14}\text{C}$  dates compiled in the database were calculated after correction for oversampling biases (see above). The results of the preparative binning process are shown in Table S1. In order to avoid edge effects related to the abrupt decline of radiocarbon date intensity toward the present day, as other dating techniques such as historical documents becomes available, the simulation results, which started from 5150 cal. yr BP were



trimmed at 400 cal. yr BP.

To assess whether the SPDs of  $^{14}\text{C}$  dates showed statistically relevant fluctuations, the SPDs were compared with an exponential model (based on 10,000 Monte-Carlo simulations) used as a conservative null hypothesis reflecting long-term prehistoric human population growth and taphonomic losses, as already proposed elsewhere (Crema *et al.* 2016; Shennan *et al.* 2013; Timpson *et al.* 2014). This method resolves numerous biases related to sampling error and fluctuations in the  $^{14}\text{C}$  calibration curve. Significant deviations (negative or positive) from the SPDs reflect changes in the population dynamics that were significantly stronger than in other periods, although these deviations are not interpreted in terms of absolute demographic change. To examine population changes in different geographic sub-regions, a non-parametric extension of this method was performed, specifically a permutation test, allowing the statistical comparison of two or more sets of  $^{14}\text{C}$  dates (Crema *et al.* 2016). In this method the null hypothesis is that the SPDs are equal in the regions compared if the sample dates are generated from identically shaped population curves (Fig. 6). Three regions were defined (North Coast, South Coast and Hinterland) based on their geographical coordinates and using a hierarchical clustering analysis in Euclidean space (Table S1 and Fig. 5). Had further regions been defined, the number of dates per region would have dropped significantly, (values before and after binning are North Coast: 526 – 215, Hinterland: 241 – 137, South Coast: 372 – 226, respectively). This consequent reducing may hamper the statistical significance of  $^{14}\text{C}$  dataset. Timpson *et al.* (2014) showed however that the method remains robust even for small sample sizes, although it may not be fully suited to detecting rapid demographic processes at the scale of a few hundred years with reduced data sets. ~~Data and source codes used in this study can be found in <https://figshare.com/>.~~ The archaeological dataset and the source codes used in this study can be found in the figshare online repository (doi: ...).

### 3. RESULTS

#### 3.1 SPD deviation of archaeological remains through time

In WCA, the SPD deviation of archaeological finds increased from 2800 cal. yr BP until around 1500 cal. yr BP when the curve suddenly fell, confirming the empirical observations of Oslisly (2014) (Fig. 2B). Based on the SPDs of calibrated  $^{14}\text{C}$  dates for the entire WCA dataset (at 95% confidence interval), a significant change in the archaeological record is

inferred, highlighting a major positive deviation in the SPD curve from 2500 to 1500 cal yr BP. This positive deviation is marked by two distinct increases (Fig. 2B) with maximum values at 2300 cal. yr BP (interval ~2500-2000 cal. yr BP) and 1700 cal. yr BP (2000-1500 cal. yr BP).

Conversely, between 1200 and 400 cal. yr BP, the SPD curve shows clearly a global negative deviation, which has been documented in all archaeological contexts as shown in previous studies (Oslisly *et al.* 2013; Saulieu *et al.* 2017). Since the dataset has been binned to avoid over- and under-representation, and since this decrease is documented across the whole region, at whatever scale of analysis, sampling bias can be ruled out.

However, it is important to note that the decrease of the values initiated earlier, from 1500 up to 1200 cal. yr BP. After this decline, a stabilisation of the curve occurred between 1200 and 800 cal. yr BP. Finally, values recovered from 800 to 400 cal. yr BP without reaching the exponential null model.

### **3.2 Archaeobotanical finds and changes in cultivation practices**

Throughout the period considered, the archaeological contexts remained homogeneous, consisting mostly of pit features (Fig. 2A). These features are about one meter in diameter and more than a meter-depth and are generally filled with black earth containing charcoal and calcined fruits, sherds, stones and sometimes iron tools. The purpose of these features is still debated (Eggert *et al.* 2006; Mbida 2003; Mbida & Mvondo Ze 2016; Saulieu *et al.* 2017), but there are several lines of evidence that pits are associated with domestic sites, and likely correspond to refuse chutes (Oslisly *et al.* 2013; Saulieu *et al.* 2017).

While pottery and pits in the domestic context in WCA first appeared around 2800 cal. yr BP (Figs. 2 and 3), recurrent archaeological elements – such as traces of *Pennisetum glaucum*, *Elaeis guineensis* nuts and iron metallurgy – arose simultaneously in different sites around ~2500 cal. yr BP and then increased sharply afterwards (Fig. 2A). Iron metallurgy is probably older in other parts of Africa (Clist 2012), notably in Nigeria (Eggert 2014). The expansion seen here therefore appears to be related to its initial introduction into the region.

The occurrence of cultigens in WCA reveals different chronological patterns. Remains of both *Pennisetum glaucum* (charred grains) and *Elaeis guineensis* (charred nuts) appeared during the first part of the positive deviation (~2500-2000 cal. yr BP). *Elaeis guineensis*, a sun-loving tree, is fundamental to the diet of Central Africa for the protein it provides and the fermented

drink it makes possible. But the origin of its use is problematic, exactly the same way as for the other important tree in the region, *Canarium schweinfurthii*, present in archaeological contexts from the early Holocene. In archaeology, it is difficult to prove that a plant that is not domesticated (in the genetic sense of the term) was really cultivated. The remains of its charred endocarp that frequently appear in sites from the second half of the Holocene are therefore not necessarily proof of true domestication. Thus, there is a long-standing debate between those who interpret the visible variations of *Elaeis* in pollen diagrams, such as that of Lake Barombi (Maley & Brenac 1998), as natural phenomena, notably climatic (*idem*, Maley & Chepstow-Lusty 2001), and those who maintain that this tree was rationally exploited and disseminated by humans and was even a marker of anthropisation of the landscapes (Warnier 1984, Sowunmi 1998). The statistical results presented here do not allow the debate to be resolved, but combined with the other trends, they could show how the landscape seems to be increasingly anthropised.

Rare *Pennisetum glaucum* remains, a cereal domesticated in northern Mali and Mauritania about 4900 years ago (Burgarella *et al.* 2018), are only present for a short time period prior disappearance (Kahlheber *et al.* 2014). Noteworthy and as expected, its occurrence in WCA postdates the one in central Nigeria (the Nok Culture) by the first half of the first millennium BC (Champion & Fuller 2018). Unfortunately, instances are too scattered and scarce to retrace the timing of its spread in WCA. This low occurrence of *Pennisetum glaucum* remains can be partly attributed to the lack of studies using dedicated isolation methods (e.g. flotation method) (Fig. 2A) (Wotzka 2019). Moreover, the populations of the Congo Basin, although theoretically cultivators, only sporadically consumed this cereal, and in a very variable way depending on the region (Bleasdale *et al.* 2020). Despite its low occurrence, the use of this non-local cereal remains an important cultural fact.

### **3.4 Timing of archaeological occurrence and cultural periods**

Twenty-one well-described ceramic traditions were compared for which more than five reliable dates were available (Fig. 3). These have been chosen from the contexts that seem most representative and have all been binned in space and time in the same way. The positive SPD deviation curve corresponds with a specific cultural period. The first half of the positive deviation, between ~2500 and ~2000 cal. yr BP, takes place within a ceramic horizon, which lasts from ~2800 to ~2000 cal. yr BP (Figs. 3 and 4). The ceramic styles predominant in this

first period share numerous formal and decorative peculiarities, present at a large regional scale. This period has different names in the literature: *Neolithic* or *Neolithic Stage* (Denbow 1990; Neumann et al. 2012; Oslisly *et al.* 2013), *Stone to Metal Age* in de Maret (1982, 1994) or *Ceramic Later Stone Age* (Denbow 2012, 2013). To avoid entering into a terminology debate that is beyond the aims of this article, the period is referred to here, for convenience, as *Neolithic*.

Despite some strong similarities, at least six distinct ceramic styles (Dibamba E, Malongo, Obobogo, Epona, Okala, Nya Zanga) occurred between ~2500 and ~2000 cal. yr BP. First described in Obobogo (Yaoundé, Cameroon; Fig. 3), ceramics are characterised by simple shapes: ovoid or spherical short-necked jars, usually with flat bases (Oslisly *et al.* 2013; Saulieu *et al.* 2017). Techniques, decorative arrangements and decorative motifs are dominated by comb or shell impressions (from vertical and/or rocker stamping) and shallow transverse linear tracings. In general, the decoration is not very neat, and the firing atmosphere generally seems to have been conducive to oxidising. The lips of containers are often fluted (Fig. 4, *p-s*). Various coeval ceramic styles in the Republic of Congo (Denbow's *Ceramic Later Stone Age 1&2*, Denbow 2013) and in the Democratic Republic of Congo (Imbonga, in Wotzka 1995) share occasional similarities and seem to be part of a common cultural area (Fig. 4, *v & w*).

The second half of the positive deviation, occurring between ~2000 and ~1500 cal. yr BP, coincides with what some authors call the *Early Iron Age*. This period is characterised by a considerable amount of iron artefacts in archaeological contexts along the coastal regions (Table S1). Yet iron artefacts in the eastern regions of WCA are rare and of later date (Fig. S1C and Table S1) (Wotzka 1995, 2006). Regardless, the ceramic styles between ~2000 and ~1500 cal. yr BP (Fig. 4, *k-o*) are diverse but they share numerous similarities (Saulieu *et al.* 2017). They comprise flat-bottomed vessels and containers with composite shapes. These usually high-necked, high-shouldered pots, sometimes carinated, and various other containers such as bowls with direct or composite walls, are characterised by a particularly rich decoration, reminiscent of the earlier Imbonga ceramic style, made with combs (sometimes broadly grooved) and sticks. The patterns (parallel lines, hatching, dots, herringbone) are very dense and often deeply imprinted in the clay. In some areas *appliqué* was used. The decorations cover the whole exterior of the jar and, often, also the inner surface of its flared edges, always with great care. Thus, ceramic styles from this second period (Figs. 3, 4) share

many formal and decorative traits at a wider regional scale.

### 3.5 Spatial occurrence of archaeological remains

At the scale of the studied region (1500 km by 1500 km), the dates of the Neolithic ceramic styles (Fig. 3) do not seem to be distributed in a clear spatio-temporal gradient that would be indicative of diffusion processes. Indeed, in the case of a diffusion from a homeland, we may expect to have a well-delimited region characterized by the oldest dates, with younger and younger dates found when moving away from this centre. However, in order to avoid subjective bias in the search for a possible spatial dynamic, a clustering analysis of geographical coordinates was undertaken. The dated items were split into the three distinct regions already mentioned, namely “North Coast”, “South Coast”, and “Hinterland” (Fig. 5). Comparisons using regional SPDs for each region (Fig. 5) and permutation tests of SPDs between regions (Fig. 6) allow two observations.

Firstly, the permutations demonstrate that the North and South Coast regions are statistically indistinguishable for both cultural periods: the positive deviations are synchronous with the inceptions (~2500 cal. yr BP), terminations of significant archaeological occurrences (1500 cal. yr BP) and present similar general shapes. This suggests that the North and South Coast actually formed a single homogenous cultural region between ~2500 and ~1500 cal. yr BP.

Secondly, the Hinterland shows a different pattern. The  $^{14}\text{C}$  SPD curve does not show the typical bimodal distribution of both coastal areas. On the contrary, it shows a single principal peak whose inception shows a slight lag of ~170 yr compared with the coastal regions, which, however, is not statistically significant. This peak is stronger and lasts longer (Fig. 6), overlapping the second peak identified in the coastal zones. Finally, the  $^{14}\text{C}$  SPD curve dips drastically at ~1300 cal. yr BP, ~200 years later than for the coastal regions (Figs. 5, 6). These identified differences between the coastal regions and the Hinterland (discernible from metallurgy, the use of *Elaeis guineensis* and from the shapes of regional  $^{14}\text{C}$  SPD curves, see Fig. 5C and Fig. S1) occurred during the Early Iron Age.

## 4. DISCUSSION

### Evidence for a possible population growth between ~2500 and ~1500 cal yr BP

The SPD curves (Fig. 2) highlight one positive deviation between ~2500 and ~1500 cal. yr, followed by a negative deviation between ~1500 and ~400 cal. yr BP. This study, therefore,

suggests a significant population growth (between ~2500 and ~1500 cal. yr BP) followed by a widespread demographic decline (between ~1200 and ~400 cal. yr BP) in WCA.

Aside from the main trends in population dynamics identified, there are also regional differences. The first part of the population growth (~2500-2000 cal. yr BP) appears marked in the two coastal regions, while the second part (~ 2000-1500 cal. yr BP), affecting all regions, is more prominent in the Hinterland (Fig. 5).

### **Cultural and technical changes tied to the population growth**

The population growth seems also to correspond with cultural and technical changes, which can be summarised in three points:

- 1- The first part of the population growth (~2500-2000 cal. yr BP), present only in the coastal regions, happens during the second half of the Neolithic period (~2800-2000 cal. yr BP) and coincides with the appearance of the cultigen / iron metallurgy package.
- 2- The second part of the population growth (~2000-1500 cal. yr BP) corresponds with the Early Iron Age in all three regions. It is worth highlighting that this period is characterised by a general change in ceramic styles in the two coastal regions.
- 3- In the coastal regions, the two parts of the population growth are associated with the cultural periods of the Neolithic and the Early Iron Age respectively. Conversely, in the Hinterland, the main population increase occurred during the Early Iron Age. These observations are consistent with archaeological data from the Democratic Republic of Congo showing the important diffusion of related ceramic styles eastwards along the tributaries of the Congo River and suggesting a colonisation movement (Wotzka 1995, 2006).

### **Unresolved question of the environmental impact of the population growth**

The first part of the population growth (~2500-2000 cal. yr BP) seems coeval with environmental and vegetation changes recorded in sedimentary archives from WCA, at least at the local scale. Indeed, various palynological records show that roughly between 3000 and 2000 cal yr BP, rainforests were replaced in many places by a forest-savannah mosaic (e.g., Vincens *et al.* 1999). The timing of this vegetation disturbance, referred to as the Late Holocene Rainforest Crisis (LHRC), is poorly constrained, mostly because of the low-scale time resolution of the sedimentary archives that were investigated and the presence of sedimentary hiatuses (Bonnefille 2011). A recent study (Garcin *et al.* 2018) confirms a

prominent and abrupt appearance of C4 plants in the Lake Barombi catchment, at ~2600 cal. yr BP, followed by an equally sudden return to rainforest vegetation at ~2020 cal. yr BP. Based on changes in carbon and hydrogen isotope compositions of plant waxes, it also shows that there was no simultaneous hydrological change during this event. This local and well-dated record suggests the concomitance between the LHRC and the first part of the SPDs positive deviation interpreted as a regional population growth (~2500-2000 cal. yr BP). However, the question of the spatial scale of this impact remains open. Kiahtipes (2019) outlined that local human disturbances near the Atlantic coast might have amplified a long-term forest fragmentation during the Late Holocene, when the climate was drier than in the earlier Holocene.

### **The Bantu expansion issue**

It is questionable whether these results can be straightforwardly integrated with current data on genetics and historical linguistics, notably with the spread of Bantu languages. This expansion is generally assumed to have taken place between 5000 and 2000 cal. yr BP (Bostoen 2018; Bostoen *et al.* 2015; de Maret 2013; Vansina 1984, 1990). The population growth highlighted from ~2500 BP onward is difficult to link with the expansion of languages in Central Africa for two main reasons. The first is that there is no ancient DNA for the populations concerned by this demographic phenomenon. The available DNA data (Lipson *et al.* 2020) are from the Shum Laka site located in the grassland of Western Cameroon, the supposed homeland of the Bantu languages and concern the immediately preceding period (8000-3000 cal. yr BP). Genome-wide DNA analyses clearly indicate that there is no direct link between the current Bantu populations and the four individuals recovered in the Shum Laka rockshelter (Ribot *et al.* 2001; Lavachery 2001). The second reason is that the statistical analysis of the archaeological data does not prove that this possible population growth is accompanied by a large migratory movement throughout the region. Indeed, the diffusion of the cultigen/iron metallurgy package co-occurring with the archaeological contexts dominated by refuse pits and accompanied by a population growth (from ~2500 to 1500 cal. yr BP) is very similar in the coastal regions. Here, it is difficult to argue in favour of diffusion because there is not one central region where all these phenomena appear first and that could play the role of a homeland. This can be explained in several ways. The first possibility is that the method of analysis is not precise enough to identify diffusion. It should be remembered that

comparison of regional curves for periods of less than two hundred years (the threshold used to avoid chronological bias), is not statistically significant. Even could we detect diffusion over such a time scale it would not solve the interpretation problem since there could have been demic (i.e., resulting from population displacements) or non-demic (without population displacement) dissemination of cultural traits or techniques (or both). A demic diffusion from the North Coast to the South Coast region would imply the displacement of sedentary populations over 1000 km in less than 200 years. Knowing the quantity of archaeological remains involved, and taking seriously into account the distances (without a navigable rivers), this does not seem to be a realistic hypothesis: the shifts would be detectable. Conversely, the dissemination of technical practices or cultural traits over such distances in less than 200 years *without* population displacement is conceivable under certain conditions. Both social anthropology (e.g., Kopytoff 1987) or analytical sociology (e.g., Hedström 2006) can provide models or examples of transmission along social networks. However, these are currently impossible to demonstrate ~~in the archaeology~~ based on available archaeological evidence. Nonetheless, if this hypothesis is retained, then it follows that the social networks that enabled the rapid diffusion of these technical practices and/or cultural traits were already in place and mature before 2500 cal. yr BP.

### **Population decline between ~1200 and ~ 400 cal. yr BP**

The negative deviation of the curve (1200-400 cal. yr BP) corresponding to a possible global decline in occupation levels is widespread and follows a millennium long trend of population growth and probable technologically-driven modification of the environment through, for example, iron metallurgy. This regional decrease may not be clearly reflected in all local archaeological records. Even if in some regions human settlements seem to be maintained (Lupo *et al.* 2018; Oslisly *et al.* 2013), there seems to be a gap in the cultural chronologies of the Lopé region of central Gabon (Oslisly 1993; Oslisly 2001; Assoko Ndong 2002) and the Dibamba site on the Cameroonian coast (Saulieu *et al.* 2017).

Changes in population dynamics in both coastal regions of WCA and in the Hinterland were asynchronous (Fig. 5). The permutation test (Fig. 6) indicates that during the first population growth the Hinterland response lagged behind the coastal regions by ~170 years (which is not statistically significant), and the population decline arrived ~200 years later. This confirms the particular status of the Hinterland region, in contrast to the two coastal regions. The latter are



actually very similar as demonstrated by the permutation test.

It must also be emphasised that the negative deviation of the curve observed between ~1200 and 400 cal. yr BP is coeval with the proposed substantial gene admixture between the rainforest hunter-gatherers ('pygmies') and the ancestors of the modern Bantu-speaking peoples, estimated between 1000 and 800 cal. yr BP (Patin *et al.* 2014, 2017). This raises a multitude of questions regarding when these different populations settled in Central Africa, as well as when and how the very particular relations that they maintain today came about. The well-known complementarity between these different populations (Bahuchet 1991; Testart 1982) could therefore have been established at that time, attributing to the pygmies the activities related to the deep forest.

The cause of this population decline is unknown. A sanitary or epidemic regional crisis could be envisaged, similar to the hypothesis of the ~~Great Plague~~ second plague pandemic ~~destroying the Ife Civilisation and many urban sites in West Africa in the 14<sup>th</sup> century~~ impacting societies in the Ife political sphere of influence, and many other urban sites in West and East Africa starting in the 14<sup>th</sup> century (Chouin 2013, 2018; Green 2018). The demographic decline should probably be seen as the result of multiple rather than single factors, as it is deep and long term. What initiated the decline and what prolonged it? The chronological framework we present coincides with the chronology of the 'First plague pandemic' (540-850 CE) as already mentioned in Saulieu *et al.* (2017). This hypothesis seems to be unsubstantiated for the moment. Moreover, as the demographic crisis is very long, it is not impossible that this event is one of the other factors in the depopulation, particularly environmental ones (e.g. Sebag *et al.* 2017). The environmental transformations triggered by these sedentary human communities could have shifted epidemiological boundaries. We could also make the hypothesis that human communities could have adopted new practices that brought them into contact with particularly virulent pathogenic vectors. However, the insufficient accuracy of the statistical method and the absence of human remains do not allow further insight.

## 5. CONCLUSION

The statistical analysis of summed probability distributions of <sup>14</sup>C dates from archaeological data in Central Africa indicates a population growth between ~2500 and ~1500 cal. yr BP.

The concomitant increase of refuse pits, *Elaeis guineensis*, and iron metallurgy along with rare remains of *Pennisetum glaucum* took place during the second half of the Neolithic, beginning around 2800 cal. yr BP. Regional differences were demonstrated by splitting the data into three geographical clusters ('North coast', 'South coast' and 'Hinterland'). In the coastal regions, the population growth appears in two successive parts during the Neolithic and the Early Iron Age (~2500-2000 cal. yr BP and ~2000-1500 cal. yr BP) while in the Hinterland the shape and timing of the curve is slightly different (~2400-1300 cal. yr BP). However, it is not possible to identify a common diffusion phenomenon from a homeland. While the specificities of the SPD curve for the Hinterland region can probably be explained by colonisation in the Congo basin (Wotzka 1995, 2006), the two coastal regions evolve in an identical way, to the extent that it seems unlikely that the archaeological proxies and the SPD curve are here indicators of a population displacement. On the contrary, it suggests a wide-ranging interaction network, already in place when new innovations arrive around 2500 cal. yr BP, causing population growth. A decline in settlements at the regional level after ~1500 cal. yr BP is also evident and detailed at a sub-regional scale. This decline can be compared with the long-term local archaeological chronology observed at the Lopé (Oslisly 1994, 1993, 2001; Assoko Ndong 2002) or Dibamba (Saulieu *et al.* 2017) sites. However, the causes are yet to be elucidated.

This study establishes for the first time a plausible picture of the population dynamics and the evolution of cultural traits and technical innovation in WCA over the last five millennia, based on a comprehensive and statistically-binned archaeological database. These results provide a robust archaeological timeframe that may contribute to the refinement of phylogenetic and linguistic models in the area. Together with ancient DNA collected recently data obtained from the Shum Laka site (Lipson *et al.* 2020), aim to also contribute to the debates regarding the cultural and linguistic history of Central African populations as well as the long-term changes in land use that affected this region during the Late Holocene.

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**Author contributions:** G.S., Y.G., D.S. and R.O. conceptualised the paper. R.O., G.S., Y.G., and P.N. built the archaeological dataset. Y.G., D.S. and G.S. performed analyses. All authors assisted with data interpretation and paper preparation. D.Z. and P.C. provided feedback on the concepts, data interpretation and paper preparation. G.S., D.S. and Y.G. wrote the paper.

**Fig. 1. Spatiotemporal distribution of sample sites covering the past 5000 years.** (A) Current spatial distribution of the rainforest shown in green, taken from the Collection 5 MODIS Global Land Cover Type product ([www.landcover.org](http://www.landcover.org)). Countries: AGO–Angola; CAR–Central African Republic; CMR–Cameroon; COG–Congo; DRC–Democratic Republic of Congo; GAB–Gabon; GNQ–Equatorial Guinea; NGA–Nigeria. Overlain are  $^{14}\text{C}$ -dated archaeological sites in WCA with dated and associated material. (B) and (C) time-latitude and time-longitude distribution of the calibrated radiocarbon dates, respectively. Horizontal and vertical bars show the 95% ranges of analytical error on the  $^{14}\text{C}$  dates. (D) Histogram of the calibrated radiocarbon age (median) distribution of archaeological sites shown with 100-year bins for WCA.

**Fig. 2. Archaeological synthesis of Western Central Africa during the past 5000 years.** All archaeological data presented rely on the SPDs of calibrated  $^{14}\text{C}$  dates that were binned in space using 10-km radii and time using 200-yr intervals. SPDs were plotted with a 200-yr moving average to prevent over-interpretation of smaller scale variability. (A) Evidence of human activity in the WCA inferred from the occurrence of remains of millet (*Pennisetum glaucum*), palm oil (*Elaeis guineensis*), iron metallurgy and pit features in archaeological context. (B) SPD-inferred population dynamics: SPD of  $^{14}\text{C}$  dates (thick line) was compared against an exponential model used as a conservative null hypothesis (see text for explanation). The dark grey area represents the 95% confidence interval for the null model. Red and blue areas represent intervals with significant positive and negative deviations from the exponential model, respectively. Regional cultural timeline (2) shown at the bottom (LSA–Late Stone Age; Neolithic S.–Neolithic Stage; EIA–Early Iron Age; LIA–Late Iron Age). (A) and (B) are

adapted from (14). The blue and red vertical lines indicate the limit of the Late Holocene Rainforest Crisis (LHRC) at Lake Barombi (SW Cameroon).

**Fig. 3. Pottery traditions and main Periods of Western Central Africa. (A)** Data shown in time. All archaeological data presented rely on the SPDs of calibrated  $^{14}\text{C}$  dates that were binned in space using 10-km radii and time using 200-yr intervals. SPDs were plotted with a 200-yr moving average to prevent over-interpretation of smaller scale variability and are shown as a greyscale (black represents maximum probability; white represents null probability). Coloured dots refer to sites on the map in (B). Regional cultural timeline shown at bottom (LSA–Late Stone Age; Neolithic S.–Neolithic Stage; EIA–Early Iron Age; LIA–Late Iron Age). The blue and red vertical lines indicate the limit of the Late Holocene Rainforest Crisis (LHRC) at Lake Barombi (SW Cameroon).

**(B)** Location and age of sample sites. Larger dots represent older samples and smaller dots represent younger samples. Colours refer to pottery traditions highlighted in (A).

**Fig. 4. Chronology of Western Central Africa with Pottery traditions. Late Iron Age:** (a, b) Dibamba A – Cameroon; (c) Lopé region from 11<sup>th</sup> to 18<sup>th</sup> centuries - Gabon, (d, e) Dibamba B - Cameroon, (f) Oku - Cameroon, (g) Dibamba C - Cameroon, (h, i) Lobéké - Cameroon, (j) Kovifem - Cameroon. **Early Iron Age:** (k, l) Campo - Cameroon, (m) Akom near Mintom, Cameroon, (n) Lalara - Gabon, (o) Otoumbi - Gabon. **Neolithic:** (p) Dibamba E - Cameroon, (q) Mpolongwé - Cameroon, (r, s) Nya Zanga - Cameroon, (t, u) Epona - Gabon, (v) Imbonga – Democratic Republic of Congo (w), **CLSA** from Madingo-Kayes – Republic of Congo. © J. Denbow (w), © R. Oslely (c, q, o, n, t, u), © G. de Saulieu (a, b, d-m, p, r, s), and © H.-P. Wotzka (v).

**Fig. 5. Regional variability in population dynamics of Western Central Africa. (A)** Map of Western Central Africa. Dots indicate archaeological site locations and colours delineate the three

regions used to estimate population changes. **(B)** Definition of the three regions based on a hierarchical clustering analysis in Euclidean space. **(C)** SPD of the three regions (thin line) against an exponential model. The thick lines show the 200-yr rolling mean and the grey area represents the 95% confidence interval for the model. Red and blue vertical bands represent periods with significant positive and negative deviations, respectively.

**Fig. 6. Comparison of SPDs of the three regions based on permutation tests.** Each row shows an observed SPD (black thick line with its model in grey) of a region compared against another in the column. Red and blue vertical bands indicate periods with significant positive and negative deviations from the model of the combined set of each of pair.

Table S1.				
	Samples ( <i>n</i> )	Sites ( <i>n</i> )	Binned sites ( <i>n</i> )	Binned dates ( <i>n</i> )
North coast	526	157	84	215
Hinterland	241	106	66	137
South coast	372	175	96	226

Table S1. Data used for the SPD analysis of each of the three regions of Western Central Africa.

Table S2.					
				Pairwise permutation test	
	Exponential null model test		<i>vs. Atlantic north</i>	<i>vs. interior</i>	<i>vs. Atlantic south</i>
North coast	<b>&lt;0.0001</b>		-	0.1527	0.2228
Hinterland	<b>&lt;0.0001</b>		0.1763	-	<b>0.0028</b>
South coast	<b>0.0002</b>		0.2970	<b>0.0026</b>	-

Table S2. Statistical significance for the exponential model and pair-wise permutation tests (values in bold are significant at 0.01).

Table S3.				
	North coast	Hinterland	South coast	
Millet				
Samples ( <i>n</i> )	16	2	0	
Sites ( <i>n</i> )	4	2	0	
Binned sites ( <i>n</i> )	3	1	0	
Binned dates ( <i>n</i> )	4	1	0	
<i>Elaeis guineensis</i>				
Samples ( <i>n</i> )	118	121	42	
Sites ( <i>n</i> )	46	44	20	
Binned sites ( <i>n</i> )	28	27	13	
Binned dates ( <i>n</i> )	58	55	25	
Iron metallurgy				
Samples ( <i>n</i> )	89	18	83	
Sites ( <i>n</i> )	50	13	63	
Binned sites ( <i>n</i> )	35	6	40	
Binned dates ( <i>n</i> )	52	7	60	

Table S3. Data used for the construction of Fig. S2.

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