Ancient deforestation in the green heart of Africa

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The forested expanses of Central Africa host the second largest block of tropical rainforest on Earth (after Amazonia), stretching over around 2×10^6 km^2. They are the great green heart of Africa, and changes in vegetation cover are likely to have important but poorly understood influences on the climate of much of the continent (1). A remarkable feature is that this blanket of forest appears quite tenuous—under the arid climates of the ice ages, the forest appears to have retreated into isolated pockets surrounded by savanna grasslands. Even in the climatically stable Holocene, there appears to have been periods of substantial forest retreat. In particular, there is evidence for a period of major forest loss between 3,000 and 2,000 y ago [termed the Late Holocene rainforest crisis (LHRC) (2)]. Attributing the cause of this decline is complicated by the fact that this period coincided with major expansion of Neolithic and early Iron Age farmers southward from the Nigeria/Cameroon border regions into western Central Africa. Did the farmers take advantage of a forest retreat driven by climate drying, or were they the primary cause of the forest loss? In recent years, there has been a vigorous debate on the cause of the LHRC. Now, Garcin et al. (3) provide new data and an unexpected new insight, presenting strong evidence that there was no strong drying event, and therefore suggesting that it was direct deforestation that caused this retreat of the Central African rainforests.

Until a few years ago, there was a broad consensus among paleoecologists and archaeologists that that the LHRC was a climate-induced event, with humans playing a marginal role at most in enhancing forest loss. This view was based mainly on interpretation of vegetation pollen from lake cores and diatom data from marine cores, together with limited archaeological data (4, 5). This consensus was challenged in 2012, when an analysis was published of weathering rates across the Congo Basin derived from a marine sediment record just off the mouth of the Congo River (6). This showed an apparent unprecedented increase in soil weathering rates during the LHRC; previously higher weathering rates were associated with wetter periods, not dryer ones. This surge in weathering was attributed to direct deforestation and appeared to be a smoking gun, indicating substantial human presence and impacts. This interpretation has been questioned. Were shifting cultivation and iron smelting really extensive enough and sufficient to cause such an enhancement in weathering (4)? Could the erosion of fossil soils have artificially generated this signal (5)? These particular points were responded to (4, 5), but the broad framework of the debate was still around the extent to which human activity exploited a climate drying to expand into the forest zone.

Histories in the Leaf Waxes

The new study injects an intriguing piece of evidence into the debate, evidence that controversially suggests that there was no climate-drying event, and the rainforest retreat was almost entirely the result of agricultural expansion. A key challenge for the interpretation of past climate change in the region has been that the same pollen data are used to infer both the nature of past vegetation, and the nature of past climate. If direct deforestation causes changes in the nature of vegetation cover, the ensuing changes in pollen signatures could possibly be misinterpreted as a change in climate. New insights could come if there were an alternative indicator of past climate that was independent of vegetation composition.

The study focuses the isotopic signatures of long-chain alkanes in leaf waxes. These alkanes (the 31-carbon alkane is a particular favorite for attention) are remarkably stable to decomposition and can persist for thousands of years as biomarkers in sedimentary records (7). An analysis of their isotopic signature yields two particular strands of information that record both vegetation and hydrological changes largely independently in the same organic molecule. The carbon isotopic signature records vegetation changes by establishing the degree to which the contributing vegetation is tropical trees (which mainly utilize the C3 photosynthetic pathway) or tropical grasses (which

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mainly utilize the C4 pathway). Most importantly, the hydrogen isotopic signature (the hydrogen–deuterium ratio) reflects the isotopic signature of contributing precipitation (8). The isotopic signal of precipitation seems a good indicator of overall dry/wet conditions: under higher rainfall regimes, the signal shifts toward lighter, more fractionated values. Hence evidence for past wetting and drying trends should be visible in the hydrogen isotopic signature.

Garcin et al. focus their attention on a 12-m core from one lake: Barombi Mbo in Southwest Cameroon. This is an important site that has been formative in the development of early ideas about the LHRC based on pollen analyses, which suggested that rainfall had halved in the region during the LHRC (9). Their analysis of the hydrogen isotopic signature of the alkanes shows a general drying trend over the Holocene, consistent with well-understood changes in solar radiation seasonality. Thanks to the shifting characteristics of the Earth's orbit and inclination, the amount of solar radiation falling on the Sahara desert during the northern summer has been decreasing over the Holocene. This weakens the land–ocean temperature contrast driving the West African monsoon, and thereby weakens the penetration and extent of the rainy seasons. Shorter-term variations in the sea surface temperatures of the eastern equatorial Atlantic induce fluctuations in this land–ocean contrast and in ensuing rainfall patterns.

As expected from previous pollen studies, the carbon isotopic analysis shows a clear signature of forest retreat during the LHRC. Over this period, the carbon isotope signature spikes up (becomes less fractionated), showing clear evidence of replacement of forest trees by C4 grassy vegetation or crops, as has been seen in previous pollen-based analyses. However, crucially, there is no simultaneous spike (toward lighter isotopes) in the hydrogen isotopic signature, suggesting no corresponding drying of the climate. This suggests that previous inferences of a drying event based on pollen analysis were misleading: vegetation change by deforestation was causing the change in pollen signature, and the climate did not dry significantly during the LHRC.

This insight is coupled with two additional strands of evidence. A marine core just offshore shows no shift in sea surface temperatures during the LHRC (inferred from the magnesium/calcium ratio of planktonic foraminiferal calcite), as would be expected if sea surface temperatures were a driver of shifting seasonality of rainfall in the region. Second, the study utilizes a newly compiled database of 460 dated archaeological sites across the region, which expands and synthesizes archaeological understanding of farmer settlements in the region. These show a substantial increase in the number of archaeological sites over the LHRC, with the advent of iron metallurgy and farming of pearl millet (*Pennisetum glaucum*), a C4 crop, around 2,400 y ago. Pearl millet farming disappeared in the region at the end of the LHRC, to be replaced after an interval by oil palm-dominated farming and more advanced Late Iron Age metallurgy. As a tree crop, oil palm does not leave a carbon isotopic signature distinct from forest trees.

Advance of the Farmers

What type of people were coming in? It seems likely that the waves of Neolithic pearl millet farmers and then Iron Age farmers (bringing iron smelting technology down from the Sahel and Sahara) provide the earliest signs of the Bantu expansion, as Bantu-speaking farmers spread southeast from the Nigeria/Cameroon border. Over the subsequent thousands of years, they eventually spread across southern and eastern Africa to be the dominant linguistic group over much of Africa. The demand for iron may itself have been a driver of deforestation, as charcoal was needed for smelting.

Can we be sure that the lack of a hydrogen isotope anomaly during the LHRC is a sure indicator of there being no drying event? Although the leaf wax alkane analysis breaks away from the dependence of inferring climate from pollen, it is still a plant-derived signature. Is it possible that pearl millet or other crops carry a sufficiently distinct hydrogen isotopic signature in their leaf waxes that confounds the interpretation in terms of rainfall? The study tries to account the uncertainty in isotopic signature induced by this isotopic signature for this vegetation shift, and concludes that any such effect would be small.

Another possibility is that the isotopic signature of precipitation is a misleading signature of total annual precipitation change, or that the total precipitation is a poor indicator of the seasonal variation of water stress, which is a more pertinent climate variable for vegetation limits. In this region, the seasonal variation in the hydrogen isotopic signature does track the seasonal variation in precipitation (10).

Overall, Garcin et al. present a provocative case that the loss of forest in Central Africa 2,000–3,000 y ago was almost entirely caused by agricultural expansion and not by climate variation. The work shows how novel analytic tools can be coupled with archaeological data to paint a prehistory of human expansion and climate change.

Garcin et al. also show that there is a broad but imperfect spatial correlation between total precipitation and the seasonality of rainfall. It is still possible, however, that these correlations were not the same in periods of the past, and that there was a shift in seasonal water stress that remains undetected by the leaf wax biomarkers.

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Wider Implications

What are the wider contemporary implications of this work? It shows how the early agricultural human footprint can be long and deep. Some parts of western Central Africa are now among the wildest places on Earth, the home of the lowland gorilla and the last major refuge of the forest elephant. The early wave of settlement may have had a hiatus around 2,000 y ago, but settlement again increased until about 400 CE before experiencing a major decline over the subsequent 500 y, perhaps caused by disease outbreaks (11). After a further recovery, the rural population again declined over the last 500 y, perhaps because of the depredations of the Atlantic slave trade and colonial-induced migration away from rural areas to roads. Many of the contemporary forests of Central Africa carry the structural signatures of this rural abandonment of the last few centuries (12). Hence, we see a long history of waves of human expansion and retreat in Central Africa, and how the forests carry signatures of this history but have bounced back when the circumstances were right.

Another implication lies around the climate sensitivity of the forests. The Congo basin has much lower rainfall than much of Amazonia or insular southeast Asia (the two other major rainforest blocks). It has been speculated that it would not take much drying for the forests to retreat and grasslands to expand (1). Evidence of a strong climate-induced drying during the LHRC would have supported this argument. The suggested lack of a drying event 2,000–3,000 y ago of course does not mean that the forests would not be sensitive to a drying if it were to occur, but it does weaken one important strand of evidence. As in the last few decades of deforestation across the tropics, it seems the direct human-induced deforestation may well be the primary cause of rainforest retreat in Central Africa many thousands of years ago.

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