Iron Age landscape changes in the Benoué River Valley, Cameroon

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Abstract

The introduction of agriculture is known to have profoundly affected the ecological complexion of landscapes. In this study, a rapid transition from C3 to C4 vegetation is inferred from a shift to higher stable carbon (13C/12C) isotope ratios of soils and sediments in the Benoué River Valley and upland Fali Mountains in northern Cameroon. Landscape change is viewed from the perspective of two settlement mounds and adjacent floodplains, as well as a rock terrace agricultural field dating from 1100 cal yr BP to the recent past (<400 cal yr BP). Nitrogen (15N/14N) isotope ratios and soil micromorphology demonstrate variable uses of land adjacent to the mound sites. These results indicate that Early Iron Age settlement practices involved exploitation of C3 plants on soils with low δ15N values, indicating wetter soils. Conversely, from the Late Iron Age (>700 cal yr BP) until recent times, high soil and sediment δ13C and δ15N values reflect more C4 biomass and anthropogenic organic matter in open, dry environments. The results suggest that Iron Age settlement practices profoundly changed landscapes in this part of West Africa through land clearance and/or utilization of C4 plants.

Keywords: Holocene; Savanna; West Africa; Agriculture; Anthropogenic soils; Niche construction; Soil carbon; Nitrogen isotopes

INTRODUCTION

The spread of agriculture across Africa is argued to have had significant impacts on its ecological systems, which include forest fragmentation and the presence of more open landscapes (for recent reviews, see Osilisly et al., 2013; Marchant et al., 2018; Marshall et al., 2018). Although human niche construction occurred during the Pleistocene (Ambrose, 2010; Crowther et al., 2018), the scope and scale of anthropogenic environmental alteration has accelerated since food production began (Boivin et al., 2016). Historical and archaeological records show that the per capita land use by pre-Industrial Revolution farmers exceed that of modern people to obtain equivalent amounts of food (Ruddiman, 2013). Gauging the impacts of agriculture on ambient prehistoric biodiversity can be difficult because taphonomic effects and imprecise lines of proxy evidence can confound interpretation of anthropogenic versus natural ecological dynamics (Foley et al., 2013). Ultimately, more ecological records that focus on the scope and scale of impacts associated with prehistoric agricultural practices are needed to provide clearer context for the interdependence of current human-ecological systems.

The region of western Africa lies south of the Sahara (approximately 15°N), north of the Gulf of Guinea, and west of 15°E. It is the area of original domestication for several important African crop species, including sorghum (Sorghum bicolor), African rice (Oryza glaberrima), and pearl millet (Pennisetum glaucum). Some of these crops ultimately spread across most of sub-Saharan Africa by ca. 1800 yr ago (Kay and Kaplan, 2015; Lander and Russell, 2018). However, there are significant gaps in our understanding of the ecological contexts of domestication for all of these plants (Manning et al., 2011). Recent attention has focused on the spread of agriculture in the northern part of Central Africa. There are two competing sets
of explanations for that spread: one holds that drier monsoon conditions after 2500 yr provided opportunities for agricultural colonists to plant in newly opened areas where tropical forest previously stood (Maley, 2002; Maley et al., 2012; Lézine et al., 2013; Bostoen et al., 2015; Grolemund et al., 2015; Cliset et al., 2018), while the other argues that humans cleared forests for fuel to produce iron and facilitate an agricultural economy (Bayon et al., 2012; Morin-Rivat et al., 2014; Kay and Kaplan, 2015; Garcin et al., 2018). Ultimately, understanding landscape formation processes within the context of domestication is critical to determine the dependence of ecological systems on specific land management practices. In addition, the debate cited above highlights the increasing interest in the degree to which natural ecosystems were altered to facilitate the expansion into different environments (see also Boivin et al., 2016). The lack of knowledge from adjacent regions at different points in time means, however, that this research in the northern parts of the tropical forest cannot be placed in broader comparative contexts, whether those be environmental or cultural.

To resolve such issues, multiple lines of proxy evidence from well-dated archaeological sites can provide a broad environmental context for the arrival of anthropogenic effects into a region concurrent with domestication. Concentrations of nutrients on the landscape at the hectare scale in settlements with livestock corrals systematically increase floral microhabitat diversity that can be quantified with satellite imagery; floral and soil transect surveys; and sedimentary, chemical, and isotopic analyses of soils (Marshall et al., 2018). Other agricultural and land use practices, such as coppicing, burning of pastures and agricultural fields, grazing livestock, and cultivation, change soil nutrient composition in ways that are not always obvious from a “macro-view” of site formation processes. Techniques such as soil micromorphology combined with geochemical reconstruction offer a comparative before-and-after perspective on the qualitative and quantitative impacts of human niche construction on the environment (Meharg et al., 2006; Ackermann et al., 2014; Solís-Castillo et al., 2015). Geochronometry of both depositional and genetic facies using optically stimulated luminescence (OSL) and radiocarbon (14C) dating, respectively, provides a temporal framework of the timing and rates of anthropogenic environmental change. Chronologically constrained datasets can provide multiple lines of correlative evidence to understand causal factors for landscape change. Using soil organic stable carbon (δ13C) and nitrogen (δ15N) isotopes and micromorphological analyses from dated contexts, this paper presents evidence from the Benoué River Valley and adjacent highlands in northern Cameroon for an anthropogenically induced turnover in soil isotopic composition associated with artificial tell mound construction beginning 1100 yr.

BACKGROUND OF THE STUDY AREA

The project area is located in northern Cameroon, in the lowland trough of the Yola Rift, draining waters from the Mandara Mountains to the north and Adamaoa Plateau to the south (Fig. 1). A Sudanian woodland to grassy woodland community characterizes the historic habitat of the region, with varying proportions of grasses (White, 1983). Woodland biomes are dominated by trees with open canopies, allowing sufficient light to support an understory of up to 40% heliophilous (sun-loving) C3 grasses and shrubs. Examples of environments that are minimally impacted by human activities are found nearby in the Benoué National Park, where savanna woodlands are characterized by dominant tree taxa, including Combretum, Terminalia, and Acacia (White, 1983). The principle vegetation types are highly dependent on water availability. Hydrophilic closed woodlands with sparse understory C3 grasses are found primarily in the river valleys, with deciduous woodlands in the upland regions. Riparian forest and closed woodlands have higher tree densities, with sparse grasses (~3%) in the understory (White, 1983; Stark and Hudson, 1985).

The greater Lake Chad region was occupied exclusively by hunter-gatherers until 4000 yr, after which farming and herding economies entered the region (MacEachern, 2012; Maley and Vernet, 2015). By 2400–2200 cal yr BP, shaft furnaces for producing iron are found in sub-Saharan western Africa (Killick, 2015), and Iron Age farmers were widely distributed across the region by 2000 yr (Russell et al., 2014; Bostoen et al., 2015). Iron Age settlement in mounds adjacent to the Benoué River Valley is traced from at least 1500 cal yr BP (David, 1981). By 1000 cal yr BP, people were planting sorghum (Sorghum sp.) and finger millet (Eleusine coracana), raising cattle (Bos taurus), goats (Capra hircus), and sheep (Ovis aries), and fishing from local streams (David, 1981).

Humans are hypothesized to be significant agents of regional landscape change in western Africa since the introduction of plant cultivation at ca. 4000 yr (Kahlheber and Neumann, 2007; Kay and Kaplan, 2015; Garcin et al., 2018), but the degree to which natural climate variability versus anthropogenic clearing was the driving factor of landscape change remains an open question. In order to examine the pace of ecological succession within the context of the emergence of agricultural economies, the present study presents soil stable isotopic and micromorphological evidence to better understand past human impacts on floral habitats and landscape change on a subregional scale.

STABLE ISOTOPES OF SOIL AS ECOLOGICAL PROXIES

The δ13C value of soil organic carbon is closely correlated with that of standing plant biomass, and has been widely used to reconstruct proportions of trees to grasses in tropical African environments (Ambrose and Sikes, 1991; Delégue et al., 2001; Runge, 2002; WoldeGabriel et al., 2009; Wang et al., 2010). Trees, shrubs, and most leafy herbaceous dicotyledonous plants, along with some shade- and cold-tolerant grasses (including Oryza rice and wheat), fix atmospheric carbon dioxide (CO2) using the C3 photosynthetic pathway to produce a three-carbon molecule in the first step of photosynthesis. This biochemical process discriminates strongly against
$^{13}$CO$_2$, so C$_3$ plants have consistently lower $^{13}$C/$^{12}$C ratios, with $\delta^{13}$C values lower than $-23\%$ versus the Vienna Pee Dee Belemnite (VPDB) standard (Kim et al., 2015). Conversely, most tropical grasses (including sorghum, millets, Digitaria sp., African rice, and savanna grasses), sedges (e.g., papyrus), and a few broadleaf herbaceous species that are adapted to strong sunlight and high temperatures use the C$_4$ pathway, which discriminates much less against the heavier isotope, and have $\delta^{13}$C values consistently higher than $-16\%$ (O’Leary, 1988). Average $\delta^{13}$C values of C$_3$ plants are approximately $-27\%$, and would have been approximately $-26\%$ in the pre-Industrial era. C$_4$-plant $\delta^{13}$C values would have been approximately $-12\%$ (Kohn, 2010). Soil organic matter decomposition is accompanied by an enrichment of $\sim 1\%$ (Natelhoffer and Fry, 1988), so soils with 100% C$_3$ and C$_4$ plant biomass have average $\delta^{13}$C values of approximately $-25$ and $-11\%$, respectively (Ambrose and Sikes, 1991).

Soil nitrogen isotope ratios in natural ecosystems are inversely correlated with rainfall and temperature, and can be used as a general index of aridity (Ambrose, 1991). Plant and soil $\delta^{15}$N values are also consistently higher in anthropogenic sediments (Commissio and Nelson, 2006), particularly in areas where domestic animals are corralled (Shahack-Gross et al., 2008; Marshall et al., 2018) and during natural leaf litter and soil organic matter decomposition (Natelhoffer and Fry, 1988; Högberg, 1997).

**METHODS**

**Archaeological survey and site documentation**

In order to investigate human-landscape interactions within the context of Iron Age settlement of West Africa, archaeological research was undertaken northeast of Garoua, Cameroon, in June and July 2014 (Fig. 2). An archaeological survey was undertaken to revisit sites initially investigated by David (1968, 1981) along the Benoué River and to collect samples for dating, micromorphology, sedimentology, and geochemistry. Documentation of site locations and attributes were made using a Trimble XH GPS unit. Details of project objectives and survey methods have been previously published in Wright et al. (2017).

The primary focus of site documentation was on the site of Langui-Tschéboua (GRA-4, 9.32°N, 13.62°E; Wright et al., 2017), an anthropic mound bisected by a seasonal stream. The mound and adjacent field site was cleaned and profiled, and the stratigraphic positions of soils and sediments across the exposure were systematically mapped. The mound was subjected to three-dimensional mapping to record lateral and vertical distribution of material culture remains. Archaeological features were documented in the site fill, and lithological units traced across the site area and to the surrounding terrace surface exposures. Site documentation extended to the adjacent terrace regions to connect mound activity areas with possible concurrent agricultural activity areas. The alluvial terraces and outlying depositional contexts were classified as “off-site” areas relative to “on-site” areas, which were anthropogenic mounds in the lowlands and artificial terraces in the uplands. By separating these contexts, we sought to constrain the spatial and temporal scale of anthropogenesis as agricultural practices spread into the region.

Sediment cores were extracted using a percussion auger from the lower terrace of the Benoué River floodplain adjacent to the site of Bé (9.30°N, 13.66°E). Samples from the Bé mound were collected 14.2 m northwest of David’s (1981)
excavation unit and achieved a depth of 204 cm below the modern ground surface (CAM-BE-Rock 8). A percussion auger core (CAM-BE-Rock 7) was also collected from the field adjacent to the main mound and measured 130 cm deep.

Site GRA-1 (9.40°N, 13.44°E), located in the Fali Mountains, was discovered during the 2014 field season. This is a rock terrace agricultural field with undecorated ceramics on the ground surface. The site was mapped with a GPS unit and samples were collected from two contexts: a soil pit excavated near the center of the site, and two auger cores located in upland swales. The soil pit was located in an area of high artifact concentration between artificial terraces constructed from stones. This pit was excavated to a depth of 35 cm below the modern ground surface, where bedrock or a boulder impeded further excavation into the subsoil. Charcoal was collected for radiocarbon dating and sediment samples for stable isotopic reconstruction were extracted from both depositional units.

Two percussion auger sample sets were collected from swale depressions within and adjacent to the site. Core CAM-GRA1-Rock 6 was augered to a depth of 100 cm below the ground surface within a rock-terraced portion of the site. The second core (CAM-GRA1-Rock 5) was augered to a depth of 60 cm in an off-site, upland swale vegetated with marsh grasses.

**OSL dating**

Seven sediment samples were collected from GRA-4 contexts for OSL dating. OSL dating determines the last time that sand grains were exposed to light via the accumulation of natural radiation energies (α- and β-particles, γ- and cosmic rays) in the defects of the crystal matrix of minerals (Aitken, 1998). Samples were collected using sample tubes (~4 cm in diameter and ~25 cm in length) that shield the sediments from light. When silicate-rich sediment is exposed to light with a wavelength of 470 nm in controlled laboratory circumstances, a photomultiplier tube counts the vacating electrons and experiments follow to estimate the time it took to accumulate the stored energy.

For Langui-Tscheboua, quartz grains with diameters of 180–250 µm were prepared in the laboratory using wet-sieving, acid treatments (10% HCl, 10% H₂O₂, and 40% HF), and density separation in sodium polytungstate at a specific gravity of 2.61, and were analyzed using a TL/OSL-DA-20 Risø reader. The single aliquot regeneration protocol (Murray and Wintle, 2000, 2003) was followed. The reconstructed total amount of stored energy, called the equivalent dose (Dₑ), was determined to be independent of the preheat temperatures between 250 and 295°C based on preheat plateau tests. The rates of radioactive decay within the mineral matrix environment, or dose rates (Dᵣ), of the samples were estimated using a Canberra Broad Energy Germanium 5030 low-level high-resolution gamma spectrometer. OSL signals were measured based on aliquots composed of several tens of quartz grains (small aliquots), and the final ages were derived using the central age model (Galbraith et al., 1999; Galbraith and Roberts, 2012). Ages reported have a 0 datum being the year AD 2014, which was when the samples were collected and analyzed. Thus, there is an inherent 64-yr offset between the radiocarbon and OSL ages.

**Radiocarbon dating**

Charcoal samples were collected for radiocarbon dating at the Illinois State Geological Survey (ISGS), Prairie Research...
Institute, University of Illinois at Urbana-Champaign. Preparation of the samples followed the standard acid-base-acid pretreatment protocol, converted into CO₂, after which they were loaded into a graphite target for accelerated mass spectrometry (AMS) analyses. The University of California-Irvine AMS Radiocarbon Laboratory performed radiocarbon analysis in which counts of 12C, 13C, and 14C were measured to determine the Libby half-life (5730 yr) by the 14C/13C and 13C/12C ratio of each sample, with corrections based on the 13C/12C ratio. The results were calibrated to 2-σ of statistical confidence corresponding to yr BP (AD 1950) using CALIB 7.1 program (Stuiver et al., 2019), which applies the INTCAL13 calibration curve (Reimer et al., 2013).

Micromorphology

Undisturbed soil samples were collected for micromorphological analysis. All water was removed from samples through acetone exchange. Samples were then impregnated using polyester “polylite 32032-00” resin. Impregnated soils were cured, sliced, bonded to a glass slide, and precision lapped to 30-μm thickness to produce a soil thin section. Following procedures laid out in the International Handbook for Thin Section Description (Bullock et al., 1985) and in Stoops (2003), soil properties were recorded semiquantitatively. Thin sections were analyzed using a Zeiss’ AxioLab.A1 with rotary stage, plane polarized light, cross-polarized light, and oblique incident light. These instruments allow identification of microscopic features, such as mineral and organic components, pedostructures, and burnt residues.

Soil carbon and nitrogen isotopes

Soil samples were prepared using methods described by Ambrose and Sikes (1991). Sediments were inspected with a low magnification stereomicroscope to identify pedogenic features, texture, structure, and anthropogenic and other inclusions (e.g., charcoal, bone, burnt soil, angular- to waterworn-clasts, carbonate nodules, and shell). Munsell colors (wet and dry) were recorded and samples were photographed on Munsell color chart pages. Samples were gently ground with ceramic mortars and pestles, to disaggregate soils, while leaving rock and mineral components intact, and sieved to pass through a 0.25-mm mesh geological sieve.

Samples of the <250-μm fraction weighing ~5 g were prepared for isotopic analysis by reaction with 1M HCl in 50 mL glass centrifuge tubes for 20 hours, beginning with one hour on a shaker table at ~1000 RPM, in order to remove carbonates. Intensity of reaction with HCl was noted after acid was initially added in order to qualitatively assess carbonate content. Samples were examined again after 20 hours to assess whether carbonates remained, as indicated by continued generation of gas bubbles. If reaction was incomplete, HCl treatment was repeated. After HCl treatment, samples were agitated and centrifuged three times with distilled water. If pH was close enough to neutral to cause clays to remain suspended, a few drops of 1M HCl were added to flocculate clays, and then agitated and centrifuged again before decanting the supernatant. Samples were dried at 70°C in a gravity oven. Weight after drying was used to calculate weight loss due to removal of carbonates and other acid-soluble fractions. This is the carbonate-free whole soil fraction. Dried samples were homogenized inside their centrifuge tubes using a glass rod as a pestle. Mortars, pestles and all glassware used for wet chemistry were cleaned in an acid bath, then fired in a kiln at 520°C for two hours before use to oxidize carbon and prevent sample carbon cross-contamination.

For isotopic analysis, samples weighing 4–5 mg were sealed in tin foil capsules and combusted in a Carlo-Erba NC-2500 Elemental Analyzer to convert organic matter into purified CO₂ and N₂. The purified gases were then transferred to a Thermo-Finnegan Delta V Plus XL isotope ratio mass spectrometer to measure stable isotope ratios. In order to monitor precision, accuracy, and replicability of isotopic analyses and weight percent C and N, each set of samples analyzed included purified amino acid international reference standards USGS 40 and 41 at the beginning and end of each run. Purified amino acid working standards (phenylalanine and serine) and thiourea were analyzed after every tenth run in this study. The analytical precision of isotopic analysis of δ13C and δ15N was 0.1 and 0.2‰, respectively. The average difference of replicates of soil samples was 0.1 and 0.4‰ for δ13C and δ15N, respectively. Weight percent C and N difference of replicates was 0.29 and 0.03‰, respectively. Many soil samples had low N concentrations and others had concentrations below detection limits. Those with the lowest measurable N concentrations have higher proportions of background derived from air, which has a δ15N value of 0‰. Therefore, the measured δ15N values reported here are likely lower than their actual δ15N values. This may also account for higher differences in wt% N of replicates. Estimates of percent C₄ biomass are considered ± 10% due to the range of variation in C₃ and C₄ plant biomass, potential recent habitat change, and variation in δ13C observed within modern sampling sites (Ambrose and Sikes, 1991).

Stable isotope values were statistically analyzed using the SIBER package in R (Jackson et al., 2011). SIBER generates standard ellipses of a distribution of data based on Bayesian random permutations of the actual data. Data were manually organized according to their geographic locations (called
groups) and communities were created based on on-archaeological site (on-site) and off-archaeological site (off-site) contexts. The creation of the ellipses was unsupervised and set to the 95% confidence interval.

RESULTS

Depositional context

Langui-Tschéboua is a mound feature bisected by the shifting course of the Mayo Badjouma seasonal stream (Fig. 3). The mound is constructed on top of a terrace, and is laterally exposed with fluvial scouring. The original elevated area of the mound was approximately 100 m along its short axis, although erosion of the site has been extensive. Fluvial incision is estimated to have removed approximately half of the total area of the mound, leaving a vertical scarp face, with continuous cultural deposits exposed to a depth of up to 5.4 m along the approximately 100-m exposure.

The stratigraphy and formation context of the Langui-Tschéboua mound has been previously published in Wright et al. (2017). In sum, there are two primary anthropogenic depositional components to the site of Langui-Tschéboua: the mound and adjacent fields. The mound is comprised of laminated lenses of sand, loamy sand and sandy loam with numerous artifacts eroding from the fill zones dating from between 1100 and 700 yr (Fig. 3, Tables 1 and 2). Bedding planes (cm-scale) were preserved in the alluvial substrate of the mound, but there were no depositional structures associated with the mound. Clay-rich lenses were identified in three units of the profile and ashy fill comprised five of the layers. Analysis of micromorphology confirmed the presence of ~2.5 m of discrete lenses of anthropogenic fill that were minimally compacted and variably rich in organic matter (Fig. 4a). Disseminated charcoal fragments and irregular contacts were also identified between layers (MM3A, MM5), but sample MM4 shows more diffuse, linear boundaries (Fig. 4b and c). The weak structure of the depositional features, poorly sorted and angular sediments, and OSL age of the mound fill that statistically overlaps with the alluvial substrate at 1-σ form the basis of interpretation that the mound was constructed as basket fill from the adjacent streambed (Wright et al., 2017). The adjacent agricultural fields are comprised of aggraded sand lining up to clay-dominant alluvium on top of which thin (<20 cm) soils develop. Micromorphological analysis finds evidence for burning of the terraces prior to soil formation, some evidence for trampling scars and redoximorphic features that typically occur in waterlogged settings.

The site of Bé was initially described by David (1968, 1981). Charcoal collected from lower and upper fill zones of the largest mound date from 1106 ± 33 14C yr

Figure 3. (color online) Langui-Tschéboua test units and sedimentologic profiles. Grain size classifications and abbreviations follow the United States Department of Agriculture taxonomy (Schoeneberger et al., 2012). A site plan map and locations of the profiled units are published in Wright et al. (2017).
Table 1. Equivalent dose, dose rate, and optically stimulated luminescence ages of samples from Langui-Tschéboua, Cameroon.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Water Content</th>
<th>Dry Weight Content</th>
<th>Waterlogged Weight Content</th>
<th>Waterlogged in vacuo</th>
<th>Total Dose Rate</th>
<th>Over-dispersion</th>
<th>Age (Gy)</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAM-GRA-14-OSL1</td>
<td>13</td>
<td>10.9</td>
<td>10.9 ± 3.3</td>
<td>10.9 ± 0.4</td>
<td>20.8 ± 1.2</td>
<td>776 ± 16</td>
<td>2.14 ± 0.08</td>
<td>0.95 ± 0.02</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL2</td>
<td>15.5</td>
<td>12.8</td>
<td>14.2 ± 0.2</td>
<td>14.2 ± 0.6</td>
<td>65.8 ± 1.5</td>
<td>1075 ± 22</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL3</td>
<td>1.6</td>
<td>7.8</td>
<td>9.9 ± 0.4</td>
<td>9.9 ± 0.4</td>
<td>65.8 ± 0.4</td>
<td>1283 ± 22</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL4</td>
<td>8.1</td>
<td>18.9</td>
<td>18.9 ± 0.3</td>
<td>18.9 ± 0.3</td>
<td>65.8 ± 0.4</td>
<td>2587 ± 22</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL5</td>
<td>96</td>
<td>70</td>
<td>89.9 ± 1.7</td>
<td>89.9 ± 1.7</td>
<td>65.8 ± 0.4</td>
<td>967 ± 20</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL6</td>
<td>221</td>
<td>179</td>
<td>179 ± 1.5</td>
<td>179 ± 1.5</td>
<td>65.8 ± 0.4</td>
<td>1799 ± 22</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
<tr>
<td>CAM-GRA-14-OSL7</td>
<td>511</td>
<td>149</td>
<td>149 ± 1.0</td>
<td>149 ± 1.0</td>
<td>65.8 ± 0.4</td>
<td>3677 ± 22</td>
<td>3.43 ± 0.11</td>
<td>0.36 ± 0.03</td>
</tr>
</tbody>
</table>

**Table Notes:**
- Depths of samples are the vertical distance from the modern ground surface.
- Dry weight content.
- Waterlogged weight content.
- Waterlogged in vacuo.
- Total dose rate.
- Over-dispersion percentage.  

**Table Sources:**
- Data from high-resolution, low-level gamma spectrometer were converted to finite matrix dose rates using conversion factors given in Olley et al. (1996).
- Cosmic ray dose rates were calculated using the equations provided by Prescott and Hutton (1994).

**Table Context:**
- Central age (±1-sigma error) calculated to years before AD 2014 (yr).
- The overdispersion percentage of a De distribution is an estimate of the relative standard deviation from a central De value in context of a statistical estimate of errors (Galbraith et al., 1999; Galbraith and Roberts, 2012).
Table 2. Radiocarbon ages from Langui-Tschéboua and Fali Mountains.

<table>
<thead>
<tr>
<th>Sample (ISGS #)</th>
<th>Depth (cm)</th>
<th>Material</th>
<th>$\delta^{13}$C</th>
<th>$^{14}$C yr BP</th>
<th>cal yr BP$^a$$^b$</th>
<th>Context</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-3306</td>
<td>189</td>
<td>Charcoal</td>
<td>$-10.9$</td>
<td>$765 \pm 20$</td>
<td>670–730</td>
<td>Mound sediment</td>
</tr>
<tr>
<td>A-3307</td>
<td>270</td>
<td>Charcoal</td>
<td>$-25.4$</td>
<td>$785 \pm 20$</td>
<td>680–730</td>
<td>Mound sediment</td>
</tr>
<tr>
<td>A-3308</td>
<td>307</td>
<td>Charcoal</td>
<td>$-22.6$</td>
<td>$780 \pm 25$</td>
<td>670–730</td>
<td>Mound sediment</td>
</tr>
<tr>
<td>A-3309</td>
<td>9</td>
<td>Charcoal</td>
<td>$-23.8$</td>
<td>$795 \pm 20$</td>
<td>680–730</td>
<td>Mound sediment</td>
</tr>
</tbody>
</table>

$^a$Radiocarbon ages calibrated using CALIB7.1 (Reimer et al., 2013; Stuiver et al., 2019).

$^b$Ages ± 2σ error

habitats from the pre-Iron Age (5900 yr) to Iron Age (700 cal yr BP) contexts with a return to C$_3$ vegetation in the upper solum (Fig. 8). The basal sediments from the mound have the lowest $\delta^{13}$C values of the mound sediments with an exponential-fit growth of $\delta^{13}$C after human occupation relating with the growth of the mound in the later periods of site formation. The control sample collected from the upper solum (modern “plow zone”) of the mound has a value of $-20.0\%e$, reflecting C$_3$ dominant vegetation. Similarly, samples collected in the upper 120 cm and 40 cm of Bé, which elevationally correlate with a radiocarbon age of 0–460 cal yr BP (P-1744), show lower $\delta^{13}$C values ($-16.7$ and $-18.0\%e$, respectively) relative to the off-site control samples collected in the adjacent fields (average $=-14.1\%e$). The on-site GRA-1 sample collected from an archaeological soil dating to 700 cal yr BP in the Fali Mountains has a lower $\delta^{13}$C value than all samples from Langui-Tschéboua ($-20.0\%e$). However, the off-site control samples have even lower $\delta^{13}$C values (average $=-22.3\%e$).

The average $\delta^{13}$C value from the off-mound control samples (excluding those extracted from the Bé floodplain) was $-19.5\%e$, while the Bé floodplain samples averaged $-14.8\%e$. The former set of controls indicates a C$_3$ environment (<50% grass), while the latter set reflects a C$_4$ grass-dominated habitat (70–90% grass). All off-site samples are presumed to come from contexts that date to within the last 1000 yr based on the preservation of laminate stratigraphy in the auger cores.

The $\delta^{15}$N values cluster into two primary groups according to where they were collected: (1) values above the mean, from the mound sediments, the upper solum of an agricultural terrace at GRA-1, and the floodplain at Bé; and (2) values below the mean, from most of the off-site samples and those from GRA-1. The former group’s $\delta^{15}$N average is 7.5$\%e$ and the latter group’s average is 3.0$\%e$. A linear regression (R function $\text{lm}$) between $\delta^{13}$C and $\delta^{15}$N indicated a moderately positive correlation ($R^2 = 0.48$).

**DISCUSSION**

Analysis of soil and sedimentologic features of mounds in the Benoué River Valley demonstrate anthropogenic effects on the landscape ecology associated with the introduction of a subsistence economy based on plant cultivation (Fig. 9). Approximately 2.5 m of the Langui-Tschéboua mound sediment accumulation are interpreted as having occurred rapidly (within a timespan of approximately 60 yr based on the radiocarbon chronology of charcoal from the fill and micromorphology). In contrast, the settlement mound of Bé, as previously reported by David (1968, 1981) and Lawn (1973), appears to have progressively aggregated over centuries, although interpretation of the upper fill accumulation rate is hampered by imprecision in the correction for atmospheric concentrations of radiocarbon after 460 cal yr BP. The stable isotopic composition of mound sediments, however, shows significant statistical overlap in associated plant communities. These results indicate that, while formation processes may have differed for the mounds, the associated landscape processes were similar, particularly for the latter phases of occupation.

Closer examination of the available evidence demonstrates that there is a time-transgressive element to the transition from a C$_3$ to C$_4$ landscape. The initial occupation (ca. 1100 yr during the regional Middle Iron Age) of Langui-Tschéboua reflects only a modest (+1$\%e$) shift in $\delta^{13}$C relative to the middle Holocene floodplain deposits, but during the primary construction and occupation phase of the mound, the values shift more significantly (>5$\%e$) toward C$_4$ vegetation (Fig. 8). We interpret this as evidence of an increasing scale of land clearance concurrent with the shift toward more agriculture and intensive human habitation of the mound. The final sample from the mound recovered 8 cm below the modern (farmed) ground surface seemingly suggests a stronger C$_3$ signature than the five samples collected below it. To support this interpretation, CORONA satellite imagery from the region taken in 1965 shows more extensive woodland than is currently present (Fig. 10). Less intensive recent habitation and cultivation of the Langui-Tschéboua mound site relative to the Iron Age appears to have promoted afforestation and the growth of C$_3$ vegetation.

The control samples and plow zone samples from the Langui-Tschéboua mound have more depleted $\delta^{13}$C values, reflecting a C$_3$ environment, relative to the mound sediments that date to ca. 700 cal yr BP. OSL samples from this portion of the floodplain date to within the last 150 yr. Micromorphological analyses of the floodplain soils, however, do not consistently demonstrate intensive cultivation based on the presence of planting scars in thin sections. Based on observations of modern land-use practices, the lower floodplain is used for transhumant karal agriculture (Kenga et al., 2005;
Gonné, 2010) and pastoralism, and is maintained as an open, grassy environment.

Off-site samples collected from GRA-1 range from $-20.0$ to $-24.7^{\circ/o}$, which indicates predominantly C$_3$ environments, while the sample collected from ca. 700 cal yr BP was $-19.0^{\circ/o}$ ($\sim$50% C$_4$). The site is currently vegetated with peanut (Vigna subterranea) plants, short grasses, and sparse tree cover and is also used for grazing livestock. The upland swale

Figure 4. (color online) Location, soil thin sections, and micrographs of the undisturbed soil samples. (a) MM2, micro-laminations indicating variability in the deposition of the sediment and differentiation in composition with Area 1 containing amorphous organic matter (Aom), while Area 2 shows development of calcite coatings and intercalation (Cal), with burnt bone also identified (BL) in the micrograph (cross-polarized light). (b) MM3, a diffused boundary between deposits were identified with (upper) Area 1 and Area 2 both show the development of Fe-impregnated hypocoatings (Hc) on large subangular peds, which contain high levels of fine material (FM) and are separated by inter-pedal voids (V; cross-polarized light). (lower) Fragments of charcoal (Ch) are displayed in the fine matrix, with the development of Fe-impregnated hypocoating (Hc) on sub-angular peds, while root (Rt) fragments are visible in channel voids (V; cross-polarized light). (c) MM5, microlaminates identified during field observations and weakly identified in thin section, with the groundmass displaying representative quartz coarse material with the development of grano-striations on these coarse fractions from the wetting and drying of clay colloids (cross-polarized light).
cored locations indicate the presence of a different vegetation regime today than the past. No materials were dated from the auger samples, so it is not presently possible to ascribe a distinct time period to the occurrence of this different vegetation regime. Within environments in the region with relatively low anthropogenic inputs, however, tree cover increases at higher elevations (Stark and Hudson, 1985). The samples analyzed from GRA-1 reflect this pattern. Within this environment, soil $\delta^{15}$N values reflect two primary biotic and abiotic processes of the nitrogen cycle.

Figure 5. (color online) (a) Mounds at Bé. (b) View of Mound 1 facing east. Photo taken from the location of CAM-Be-Rock 7. (c) Mound 1 excavation digitized from David (1981), showing positions of calibrated radiocarbon ages from Lawn (1973). CAM-Be-Rock 8 samples were collected from the upper 2 m of fill 14.2 m west of David’s (1981) Unit 1.

Figure 6. (color online) Fali Mountains site (GRA-1) showing: (a) plan map of site, (b) location of shovel test, (c) photo of excavated shovel test, and (d) profile schematic of shovel test with location of AMS age ISGS A-3309 (680–730 cal yr BP) denoted by a star.
High values (Langui-Tschéboua mound, Bé floodplain and mound, and the uppermost sample from the upland swale off-site from GRA-1) are interpreted as $\delta^{15}$N-enriched as a result of anthropogenic habitation activities in the case of the former group, and/or dung-enriched soil formation. Lower values from the control samples and upland settings demonstrate comparatively less intensive anthropogenic inputs into the soil. Terraces adjacent to the Langui-Tschéboua mound (TU1, TU2) have common redoximorphic weathering features, which indicate waterlogging and therefore would have been a suboptimal location for sustained human activity.

Interpretation of the stable isotopic data must be considered in the context of the drivers of regional land cover change. Lacustrine proxy data from the Adamaoua Plateau demonstrate that the Late Holocene was a period of overall forest fragmentation relative to the more humid Middle Holocene African Humid Period (AHP), which had denser tree cover (Lebamba et al., 2016). In northern Cameroon and portions of western Africa located at similar latitudes, the termination of the AHP resulted in the expansion of grasslands at the expense of woodlands (Maley and Vernet, 2015). The arrival of farmers and their associated technologies is argued to have corresponded to the expansion of C4 grasslands associated with this transition (Grollemund et al., 2015). It is also argued that anthropogenic burning encouraged this transition within the context of fragmentation of the Congo rainforest in Central Africa (Garcin et al., 2018).

The results from the Benoué River and Fali Mountains indicate changes in vegetation structure concurrent with intensification of Iron Age settlement and subsistence practices. A phase of apparent rapid mound construction at Langui-Tschéboua appears to correlate with a transition from C$_3$ to C$_4$ vegetation and anthropogenic inputs on the site and surrounding landscape. A similar, though less profound change is also indicated at GRA-1. The only sample inferred as corresponding to the occupation of the archaeological site shows the highest $\delta^{13}$C values. Samples from the floodplain of Bé, stratigraphically interpreted as likely relating to the Iron Age and later, demonstrate strong C$_4$ signatures relative to floodplain soils analyzed from Langui-Tschéboua. After the Iron Age, Langui-Tschéboua appears to have become depopulated and C$_3$ vegetation returned to the landscape, either through afforestation (Fig. 10) and/or the introduction of non-native C$_3$ crops. These results signal that, as settlement accelerated at Bé after 1000 yr, more extensive land clearance activities associated with plant and animal cultivation took root. The scale of the transformation captured within the short period (<60 yr) of formation of the Langui-Tschéboua mound suggest the observed transition exceeded the rate of change expected from natural (i.e., orbital) parameters alone. Although there is no available local hydrologic proxy data, regional indicators do not show significant changes in precipitation after 1000 yr (Lézine and Casanova, 1989; Armitage et al., 2015; Lebamba et al., 2016), which reduces the possibility that natural climate changes are responsible for vegetation succession in the Benoué River Valley. Therefore, we interpret human activities associated with land clearance for farming and mound construction as the primary drivers of the change in land cover from the sites of Langui-Tschéboua and Bé.

CONCLUSION

On-site and off-site depositional contexts along the Benoué River Valley and uplands indicate the transition from a C$_3$ (tree-dominant) to C$_4$ (grass-dominant) ecological setting in tandem with a phase of rapid mound accumulation. The time-transgressive shift from a C$_3$ to C$_4$ environment in the lowlands during the Late Iron Age is not detected at a coevally occupied site in the adjacent Fali Mountains where relatively more C$_3$ land cover remains. The differing rates of ecological shifts identified from lowland and upland settings appear to

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**Figure 7.** $\delta^{15}$N‰ (vs. AIR) and $\delta^{13}$C‰ (vs. VPDB) for samples collected in on-site (filled shapes) and off-site (open shapes) samples for Bé (blue circles), GRA-1 (red squares), and Langui-Tschéboua (black triangles). Standard ellipses generated in the SIBER package in R (Jackson et al., 2011) at the 95% (2-σ) confidence interval. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
Table 3. Stable $\delta^{15}$N, $\delta^{13}$C isotopes, and sedimentological context from the Upper Benoué region of northern Cameroon.

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<th>Lab number</th>
<th>Field number</th>
<th>Context</th>
<th>Depth (cm below surface); sediment description</th>
<th>Inferred age (yr)*</th>
<th>wt% N</th>
<th>$\delta^{15}$N_AIR (%e)</th>
<th>wt% C</th>
<th>$\delta^{13}$C_VPDB (%e)</th>
<th>Atomic C:N</th>
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<td>UIUC001</td>
<td>BE-7-1</td>
<td>Agricultural field next to Bé</td>
<td>3–6; dense clay, no sand</td>
<td>&lt;1000?</td>
<td>0.10</td>
<td>5.5</td>
<td>1.49</td>
<td>-14.6</td>
<td>16.67</td>
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<td>UIUC002</td>
<td>BE-7-2</td>
<td>Agricultural field next to Bé</td>
<td>20–23; dense clay, no sand</td>
<td>&lt;1000?</td>
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<td>3.5</td>
<td>1.01</td>
<td>-13.9</td>
<td>17.96</td>
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<td>UIUC003</td>
<td>BE-7-3</td>
<td>Agricultural field next to Bé</td>
<td>52–55; dense clay, no sand</td>
<td>&lt;1000?</td>
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<td>7.9</td>
<td>0.57</td>
<td>-14.2</td>
<td>16.69</td>
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<td>UIUC004</td>
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<td>83–87; dense clay, some fine silt</td>
<td>&lt;1000?</td>
<td>0.04</td>
<td>6.7</td>
<td>0.61</td>
<td>-13.8</td>
<td>17.65</td>
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<td>SNU1</td>
<td>BE-8-2</td>
<td>Bé mound</td>
<td>120–122; silty sand</td>
<td>0–460 (P-1744)</td>
<td>0.06</td>
<td>9.1</td>
<td>0.56</td>
<td>-16.65</td>
<td>10.89</td>
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<td>Bé mound</td>
<td>40–42; laminated sand</td>
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<td>-17.98</td>
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<td>SNU3**</td>
<td>BE-8-4</td>
<td>Bé mound</td>
<td>200; coarse sand</td>
<td>320–520 (P-1557)</td>
<td>0.08</td>
<td>6.4</td>
<td>0.02</td>
<td>-16.13</td>
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<tr>
<td>UIUC021</td>
<td>GRA1-4-2</td>
<td>GRA-1 subsoil with charcoal and ceramics</td>
<td>9; poorly sorted coarse sand; semi-rounded grains</td>
<td>680–730 (A-3309)</td>
<td>0.04</td>
<td>2.5</td>
<td>0.45</td>
<td>-19.0</td>
<td>13.01</td>
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<td>UIUC010</td>
<td>GRA1-5-1</td>
<td>Off-site GRA-1 colluvium</td>
<td>5–8; gritty sandy clay, angular-to rounded-quartz, and feldspar grains</td>
<td>Unknown</td>
<td>0.05</td>
<td>3.5</td>
<td>0.63</td>
<td>-22.5</td>
<td>14.30</td>
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<td>UIUC011</td>
<td>GRA1-5-2</td>
<td>Off-site GRA-1 colluvium, but contains wood, grass, charcoal, bone</td>
<td>22–25; massive, poorly sorted, gritty clay-silt</td>
<td>Unknown</td>
<td>0.24</td>
<td>0.8</td>
<td>3.77</td>
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<td>UIUC007</td>
<td>GRA1-6-1</td>
<td>Agricultural terrace in GRA-1</td>
<td>9–13; clayey, pelletoidal, silty sand</td>
<td>Unknown</td>
<td>0.08</td>
<td>7.4</td>
<td>1.28</td>
<td>-20.0</td>
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<td>UIUC009</td>
<td>GRA1-6-3</td>
<td>Agricultural terrace in GRA-1</td>
<td>73–76; gritty, clayey silt, mottled</td>
<td>Unknown</td>
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<td>UIUC013</td>
<td>GRA1-5-3</td>
<td>Offsite GRA-1 colluvium</td>
<td>47–51; coarse angular sand and grit in clay matrix</td>
<td>Unknown</td>
<td>0.05</td>
<td>2.2</td>
<td>0.62</td>
<td>-21.2</td>
<td>15.43</td>
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<td>UIUC015</td>
<td>LAN-TU1-2</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>94; very dark brown clay</td>
<td>140 ± 10 (OSL4)</td>
<td>0.07</td>
<td>4.3</td>
<td>1.14</td>
<td>-17.5</td>
<td>20.10</td>
</tr>
<tr>
<td>UIUC016</td>
<td>LAN-TU1-3</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>59; massive fine sand/silty clay</td>
<td>50 ± 10 (OSL3)</td>
<td>0.05</td>
<td>3.5</td>
<td>0.76</td>
<td>-18.1</td>
<td>17.85</td>
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<td>UIUC017</td>
<td>LAN-TU1-4</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>49; fine sandy silty clay/sand, pinhole voids</td>
<td>&lt;50 (OSL3)</td>
<td>0.05</td>
<td>2.8</td>
<td>0.68</td>
<td>-16.8</td>
<td>17.27</td>
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<td>UIUC018</td>
<td>LAN-TU1-5</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>18; fine silty sand, well-sorted; almost no clay</td>
<td>&lt;50 (OSL3)</td>
<td>0.07</td>
<td>4.1</td>
<td>0.97</td>
<td>-20.0</td>
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<td>UIUC019</td>
<td>LAN-TU1-6</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>3; fine silty sand, well-sorted; slightly more clay</td>
<td>&lt;50 (OSL3)</td>
<td>0.10</td>
<td>3.7</td>
<td>1.34</td>
<td>-20.7</td>
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<td>UIUC028</td>
<td>LAN-TU2-7</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>56; semi-massive to weak crumb; dark brown silty clay, small percentage sand</td>
<td>&lt;80 (OSL2)</td>
<td>0.05</td>
<td>1.4</td>
<td>0.85</td>
<td>-17.0</td>
<td>18.82</td>
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<td>UIUC029</td>
<td>LAN-TU2-8</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>44; fine sandy silt with weaker crumb structure than UIUC028</td>
<td>&lt;80 (OSL2)</td>
<td>0.06</td>
<td>3.8</td>
<td>0.88</td>
<td>-17.1</td>
<td>18.52</td>
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<td>UIUC031</td>
<td>LAN-TU2-10</td>
<td>Off-site terrace Langui-Tschéboua</td>
<td>8; silt/clay with well-sorted fine sand</td>
<td>&lt;80 (OSL2)</td>
<td>0.09</td>
<td>3.2</td>
<td>1.24</td>
<td>-19.4</td>
<td>15.64</td>
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<td>UIUC032</td>
<td>LAN-TU3-1</td>
<td>Langui-Tschéboua mound</td>
<td>511; medium/coarse poorly sorted sand; small % silt/clay</td>
<td>5900 ± 400 (OSL7)</td>
<td>0.08</td>
<td>0.8</td>
<td>0.08</td>
<td>-22.6</td>
<td>-</td>
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<td>UIUC033</td>
<td>LAN-TU3-2</td>
<td>Langui-Tschéboua mound</td>
<td>480; medium/coarse poorly sorted sand; slightly higher % silt/clay</td>
<td>1100 ± 100 (OSL1)</td>
<td>0.10</td>
<td>0.1</td>
<td>11.00</td>
<td>-20.5</td>
<td>-</td>
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<td>UIUC034</td>
<td>LAN-TU3-3</td>
<td>Langui-Tschéboua mound</td>
<td>381; medium/coarse poorly sorted sand; slightly higher % silt/clay</td>
<td>&lt;1100 ± 100 (OSL1), &gt;670–730 (A-3308)</td>
<td>0.07</td>
<td>11.4</td>
<td>0.65</td>
<td>-19.5</td>
<td>11.29</td>
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<td>UIUC035</td>
<td>LAN-TU3-4</td>
<td>Langui-Tschéboua mound</td>
<td>328; medium/fine well-sorted silt with voids and root marks</td>
<td>ca. 670–730 (A-3308)</td>
<td>0.06</td>
<td>6.3</td>
<td>1.16</td>
<td>-15.9</td>
<td>21.90</td>
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<td>UIUC036</td>
<td>LAN-TU3-5</td>
<td>Langui-Tschéboua mound</td>
<td>307; massive gray ashy fine sandy silt</td>
<td>670–730 (A-3308)</td>
<td>0.05</td>
<td>8.9</td>
<td>1.39</td>
<td>-13.8</td>
<td>34.10</td>
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**Table 3.** Continued.

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<th>Field number</th>
<th>Context</th>
<th>Depth (cm below surface); sediment description</th>
<th>Inferred age (yr)*</th>
<th>wt% N</th>
<th>(\delta^{15}N_{AIR}) (‰)</th>
<th>wt% C</th>
<th>(\delta^{13}C_{VPDB}) (‰)</th>
<th>Atomic C:N</th>
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<td>UIUC037</td>
<td>LAN-TU3-6</td>
<td>Langui-Tschéboua mound</td>
<td>259; fine silty clay; pinhole voids, termite channels</td>
<td>680–730 (A-3307)</td>
<td>0.24</td>
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<td>LAN-TU3-7</td>
<td>Langui-Tschéboua mound</td>
<td>232; fine ashy silt-clay; pinhole voids, charcoal flecks</td>
<td>670–730 (A-3306, A-3307)</td>
<td>0.05</td>
<td>7.9</td>
<td>0.66</td>
<td>–15.8</td>
<td>16.18</td>
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<td>LAN-TU3-8</td>
<td>Langui-Tschéboua mound</td>
<td>182; mottled sandy silt/clay; poorly sorted, coarse, rounded sand grains</td>
<td>670–730 (A-3306); 5800 ± 400 (OSL6—discarded)</td>
<td>0.48</td>
<td>–15.4</td>
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<td>Langui-Tschéboua mound</td>
<td>99; clayey silt with poorly-sorted subrounded sand grains</td>
<td>&lt;670–730 (A-3306)</td>
<td>0.46</td>
<td>–15.4</td>
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<td>0.46</td>
<td>–15.4</td>
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Replicates

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<td>LAN-TU3-7</td>
<td>Langui-Tschéboua mound</td>
<td>232; fine ashy silt-clay; pinhole voids, charcoal flecks</td>
<td>670–730 (A-3306, A-3307)</td>
<td>0.05</td>
<td>8.1</td>
<td>0.66</td>
<td>–15.7</td>
<td>16.20</td>
</tr>
<tr>
<td>UIUC039</td>
<td>LAN-TU3-8</td>
<td>Langui-Tschéboua mound</td>
<td>182; mottled sandy silt/clay; poorly sorted coarse rounded sand grains</td>
<td>670–730 (A-3306); 5800 ± 400 (OSL6—discarded)</td>
<td>0.05</td>
<td>8.0</td>
<td>0.66</td>
<td>–15.8</td>
<td>16.46</td>
</tr>
<tr>
<td>UIUC041</td>
<td>LAN-TU3-10</td>
<td>Langui-Tschéboua mound</td>
<td>8; fine/medium silt with poorly sorted sand grains</td>
<td>&lt;670–730 (A-3306)</td>
<td>0.12</td>
<td>6.6</td>
<td>1.77</td>
<td>–19.9</td>
<td>17.26</td>
</tr>
</tbody>
</table>

Average

| | | | | | | | | Atomic C:N |
| | | | | | | | | |

| | | | | | | | | |

**For OSL ages, 0 BP = AD 2014. For \(^{14}C\) ages, 0 BP = AD 1950**

**Although wt% C is anomalously low, its N concentration and \(^{13}C\) and \(^{15}N\) values are similar to other samples in this study. It is likely that wt %C may have been transcribed incorrectly, but the primary records for the samples were not archived, so we cannot confirm this.**
relate to the intensity of archaeological settlements in the different regions. Stable nitrogen isotopes likewise indicate isotopic enrichment of intensively farmed floodplain and mound contexts relative to extensively used landforms with stronger C₃ signatures or soils formed in rapidly aggraded, sandy bed load sediments. Overall, based on the available evidence, we interpret the mound and adjacent floodplains as being the most intensively occupied portions of the Benoué landscape during the Iron Age. Following an inferred regional depopulation and afforestation following the Iron Age, the floodplain has been used more extensively for karal agriculture and grazing.

Although the observed environmental variation is based on a limited isotopic dataset, these data demonstrate the potential for prehistoric human settlement practices to alter endemic ecological systems rapidly and profoundly and exploit different plant communities at different times. There is mounting evidence that land burning and clearance was substantial during the Iron Age and sufficient to alter local ecologies (Bayon et al., 2012; Morin-Rivat et al., 2014; Kay and Kaplan, 2015). There is considerable debate, however, about whether forest fragmentation occurred prior to or concurrent with the spread of farmers across Central Africa (Maley, 2002; Lézine et al., 2013; Bostoen et al., 2015). Our data suggests that as land settlement activities (e.g., mound construction) intensified, there was a concomitant shift to a C₄ savanna ecosystem. If this pattern bears out across the region, there are significant implications for the nature of domestication of African landscapes and the degree to which humans and their domesticates are interdependent. As the scale and scope of the human footprint increases across the planet, biodiversity in all its forms must be quantified and contextualized to better understand sustainability in landscape processes.

Figure 8. (color online) δ¹³C and δ¹⁵N isotopic profile of Langui-Tschéboua. The earlier proxy (5900 yr) is from the underlying alluvial substrate.

Figure 9. Local and regional human ecologies relative to the Benoué River floodplain, northern Cameroon. Data sources: †, David (1981); *, Armitage et al. (2015) and Lézine and Casanova (1989); **, Lebamba et al. (2016) and Armitage et al. (2015).

Figure 10. (color online) CORONA satellite image DS1027-1010DA132, taken December 10, 1965 (49 yr on the OSL clock) of Langui-Tschéboua (Fig. 2), with reference to 2014 test units (Wright et al., 2017). The mound location (Unit 3) was vegetated in forest (C₃) at the time of the satellite image. Lateral movement of the river has truncated Iron Age terraces within the last 50 years.
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SUPPLEMENTARY MATERIAL

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REFERENCES


