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Research Article

Tree demographics and soil charcoal evidence of fire disturbances in an inaccessible forest atop the Mount Lico inselberg, Mozambique

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Societal Impact Statement

Most of the highland forests of Mozambique have been strongly modified by human activities for millennia. Some Mozambican highlands have sheer rock cliffs and are highly inaccessible to people and have ecosystems with a high societal, ecological, and conservation value. Changing hydroclimatic conditions that generate fog and deliver water droplets to highland forests control the probabilities of fire ignition by lightning and from embers arriving by convection from fires in the lowlands. The forests are known to host high biodiversity and were thought to be rather pristine and undisturbed and the fieldwork evidence suggests very limited little direct human impact on Mount Lico. There are co-benefits for both ecosystems and people living around the inselbergs and these biological ‘gems’ are clearly a focus for conservation effort with the benefits needed to accrue for people living close to these forests and across the wider landscape.

Alternative Language Societal Impact Statement

*The authors would like to request a Portuguese language “Alternative Societal Impact Statement” from the Central Office of the journal to be published alongside the English version.

Optional Plain Language Summary

Mozambique has some mountain forests that few people have visited and have not been changed by human activities. The forest trees and the soil underneath them record evidence that the forests began to change during the past 2000 years and forest fires began to happen more often . Globally, relatively undisturbed forests are a rarity and should be viewed as a national and international treasure.

Summary

(1) Research aims and rationale

The sheer rock cliffs of the Mount Lico inselberg, northern Mozambique, is relatively inaccessible to people. A 0.57 km^2 forest covers the top of the isolated mountain and the tree demographics and soil offer an opportunity to investigate the long term fire ecology of the forests of the western, leeside of the mountain and potential for changing regional hydroclimate of the Late Holocene.

(2) Methods

On the western side of the mountaintop, a 20x20 m plot was surveyed for tree taxa , heights, and bole diameters. A 220 cm deep pit was dug into the forest soil and analysed to describe the soil texture and carbon content. Charcoal was quantified on sieved subsamples and classified into charcoal morphologies that were then grouped by how readily entrainable on an index score. Three radiocarbon dates were collected from pieces charcoal.

(3) Results

The forest is a combination of montane and woodland tree taxa that differed from the older, more mesic eastern side and reflected differential disturbance patterns. The reddish loam soils dated to the Middle Holocene. Charcoal was present in all soil subsamples and varied little until increasing consistently during the past millennium. The charcoal morphologies suggested a combination of locally-derived charcoal and charcoal derived from the surrounding lowlands with the latter increasing in the past centuries.

(4) Main conclusions

Few Holocene paleoenvironmental records have been developed from tropical soils in Africa and are useful in locations that do not host lakes and wetlands. Both tree demographics and soil charcoal suggest that changing forest disturbance regimes began during the past millennium. An understanding of history informs future conservation and appropriate management of these special places.

KEYWORDS charcoal morphology, disturbance ecology, embers, entrainment, forest fires, refugia, taphonomy, tropics

1 INTRODUCTION

1.1 Highland forests of northern Mozambique

Southeastern Africa ecosystems have a high conservation value (Burgess et al., 2004; Darbyshire et al., 2019; Timberlake et al., 2019; Bayliss et al., 2024) and the highlands are biodiversity refugia from land conversions and land-use pressures (Timberlake et al., 2012; Bayliss et al., 2014; Bayliss et al., 2022; Finch et al., 2014; Allan et al., 2017). Several mountain areas are physically difficult to access and have had limited anthropogenic modifications, relative to lowlands (Burgess et al., 2007; Timberlake et al., 2019). Soils that accumulate on inaccessible rock outcrops, such as steep kopjes and larger inselberg massifs (Migoń et al., 2017), are potential geoarchives for paleoenvironmental research (Marchant et al., 2018) and have been used for archaeological analyses in eastern and southern Africa (Bower, 1973; Bower and Chadderdon, 1986; Calabrese, 2000). Previous paleoenvironmental investigations of tropical soils in Kenya and Tanzania have shown the potential of soil profiles to archive past environmental changes (Cooremans and Mahaney, 1990; Zech, 2006; Zech et al., 2011; Montade et al., 2018). Soils and other deposits are important geoarchives in regions with few permanent water bodies that accumulate uninterrupted stratigraphies (Williams 1996; McLachlan and Ladle 2009; Marchant et al., 2018; Heckmann, 2014; Courtney Mustaphi et al., 2021a and b; Githumbi et al., 2021). This is especially true in southeastern Africa at lower montane elevations that tend to host few to no permanent lakes (McLachlan and Cantrell, 1980; McLachlan, 1988).

Many of the highland forests of Mozambique are relatively new to scientific exploration and very isolated forests have high biodiversity (Bittencourt-Silva et al., 2020; Daniels et al., 2020; Bayliss et al., 2024) and a target for conservation (Timberlake et al., 2019). The South East Africa Montane Archipelago (SEAMA) is a distinct montane ecoregion of granitic inselbergs with an elevation range of 500–3002 m above sea level that host humid forests and many endemic species (Bayliss et al., 2024). Some of the small and relatively isolated forested highlands of northern Mozambique have a variable degree of human modification and have been a focus of ecological research in the past few decades (Bayliss et al., 2014; Conradie et al., 2016; Jones et al., 2017; Timberlake et al., 2016). Some mountains that are highly inaccessible to humans have very little conspicuous evidence of modification by people in the past, including fires. There have been few observations and studies of montane ecological disturbance regimes, such as rapid mass movements, herbivory pressures, blowdowns, diseases, and fires — caused naturally or anthropogenically. Prior to the wide scale land conversion to agriculture in the lowlands, a shifting frontier of patchworked and overlapping land uses that included Late Neolithic and Iran Age hunter-gatherer, herder, and agricultural modes from the Mid-to-Late Holocene onward (Morais, 1984; Spear, 2000; Lane, 2004; Sinclair et al., 2014; Chami and Ntandu, 2018). These changes brought different relationships with fire that have yet to be studied in detail but are acknowledged as an important modification to the human-environment relationships of the region (Archibald et al., 2012). This study reports on tree stand demography plots, soil texture, and charcoal analyses of a 220 cm soil pit on Mount Lico, Mozambique, which provided an 8000-year record of past forest fires on the western , slightly drier leeside of the inselberg. The combination of tree demographics, soil charcoal radiocarbon dates, and charcoal morphologies, are used for an interpretation of local fire patterns of an isolated montane forest with limited direct anthropogenic modifications.

1.2 Study site

A multidisciplinary research team and professional climbers made the first scientific exploration of the forest on Mount Lico, Zambezia Province, northern Mozambique (May 2018; Timberlake et al., 2019; National Geographic, 2020). Mount Lico is a relatively small inselberg (Figure 1) formed by the erosion of Precambrian migmatitic granite, with some inclusions of metamorphosed rock and dolerite intrusions, that has a nearly vertical 700 m sheer rock face (Figure 1a) (Instituto Nacional de Geologia, 1987). The highest elevation is near the northeast side at ~1080 m asl and the mountain top is slightly undulated and hosts a forest that is important for orographic and ecohydrological precipitation. The cloudy forest moisture recharges a permanent spring and small stream that then falls to the surrounding lowland landscape to ~600–500 m asl (Figure 1e). The mountain top has a 960 m long axis (NW–SE) and 730 m short axis (NE–SW) with a general south-west aspect of the slope, and the prevailing moist south-easterly air circulates from the Mozambique Channel some 200 km away. The difficult verticality has limited anthropogenic land use and modifications and the direct exploration history is relatively uncertain (Miller, 1974; Abbott and Ruggeri, 2002; Timberlake et al., 2019). The excursion also observed pottery *in situ* that ostensibly predated recorded history and appears to be ceremoniously placed but remains to be studied in detail (Barbee, 2018).

Mount Lico is covered by 57 ha continuous sub-montane (1000–1400 m) moist forest, although slightly toward the drier conditions, and the steep cliff sides host occasional lithophytic woody shrubs, grasses and ferns on very limited soils within rock crevices (Figure 1e; Timberlake et al., 2019). The uppermost vegetation is dominated by moist forest species such as *Erythroxylum emarginatum*, *Macaranga capensis*, *Newtonia buchananii* and *Psychotria zombamontana*, with miombo taxa (*Brachystegia spiciformis*) on the western side, and few lianas. Within the forest, the shrub and herb layer are poorly developed (Timberlake et al., 2019) and rather shady (Figure 1c–d). Ignitions are possible from lightning strikes and embers transported by convection. The mountain is surrounded by miombo woodlands, introduced *Eucalyptus*, and agriculture (Figure 1b and 1e) (Bittencourt-Silva et al., 2020). Regional rainfall has an interannual range of 1107–2036 mm yr^{-1} (Reddy, 1984; Westerlink, 1996). A regional estimated length of growing period for the Ile area is 270 days per year (Voortman and Spiers 1981) and an effective dry season length of ~5 months. The potential evapotranspiration (PET) value of 1358 mm per year (Westerlink, 1996) for lowlands is likely buffered at higher elevations, >900 m asl, by orographic cloud bases (Timberlake et al., 2019).

2. MATERIALS AND METHODS

2.1 Sampling in the field

On 16 May 2018, a 20x20 m plot centred at 15.79137 °S, 37.36000 °E (1018 m asl, south facing, 20° slope) was surveyed for the tree species, heights, bole diameters, and used to calculate basal area coverage (trees >5 cm dbh) (Figure 1c–e). The tree demographic survey data was also analysed with >8 cm dbh for comparison and to intercompare with other studies. Plant nomenclature follows Burrows et al. (2018) or current usage at the Kew Herbarium, United Kingdom. At this forest plot, a 220 cm deep pit was dug with a hand shovel into the forest soil (Figure 2; geographic coordinates 15.791330 °S, 37.360044 °E, WGS84, 1018 m asl). Because of time and resource constraints, the exploratory digging had to stop before bedrock was reached and we estimated there was >30 cm soil depth by physically probing the pit bottom. Soil samples (n=33) were collected into metal containers (7x4x4 cm dimensions) from the open pit face from 3–202 cm depth at 7 cm intervals, each with 1 cm of overlap. Soil samples were shipped to Bangor University and University of York, United Kingdom. In the laboratory the containers were reassembled into a soil profile and subsampled for analyses.

2.2 Soil characterisation, radiocarbon dating, and soil charcoal analysis

Characterisation of the soil profile was done by removing subsamples from a central depth interval of each container and volumetrically measured for loss-on-ignition analysis, clastic particle size distributions, and charcoal analysis. To estimate soil accumulation rates, three subsamples of bulk soil were radiocarbon dated by accelerator mass spectroscopy at DirectAMS, Bothwell, WA, USA.

Soil bulk density was estimated with a known volume and dry weight (after drying for 24 hours at 105 °C). Loss-on-ignition analysis used dried subsamples by burning the sample at 400 °C for four hours in a muffle oven to estimate the organic carbon content (Heiri et al., 2001). Clastic particle size distributions were measured from 1 cm^3 subsamples (n=33) that were digested with 30% hydrogen peroxide and dispersed with sodium hexametaphosphate solution (Syvitski, 1991) and loaded into a Mastersizer 2000 laser granulometer (MEH/MJG180914), measured in triplicate and averaged. The percent clay (<4 μm), silt (4–63 μm), and sand size fractions (63–2000 μm) were calculated with GRADISTAT (Blott and Pye, 2001).

Subsamples of bulk soil from three depths were radiocarbon dated by accelerator mass spectroscopy at DirectAMS, Bothwell, WA, USA. Radiocarbon measurements were internally corrected by the laboratory for isotopic fractionation with measured ^{13}C measurements with the AMS. The ages were calibrated with the Southern Hemisphere SHCal20 curve (Hogg et al., 2020). Estimates of soil accumulation rates were estimated within based on linear interpolation between the calibrated radiocarbon ages generated with the ‘clam’ package version 2.5.8 (Blaauw, 2010) in R script (R Development Core Team, 2021).

For charcoal analysis, subsamples of 2 cm^3 were taken from each container down the soil pit profile (n=33) and processed with diluted hydrogen peroxide and sodium hexametaphosphate (Bamber, 1982; Schlacter and Horn, 2010) and were wet sieved with stacked meshes of 500, 250 and 125 μm. The retained content of each of the sieves were transferred to a Petri dish and the charcoal was counted under a Leica S9E stereomicroscope at 10–40× magnifications. A magnet was used to separate mafic magnetic minerals (Whitlock and Larsen, 2001; Hawthorne et al., 2018). Very large charcoal were visually categorised with a graticule into size classes of 500–1000 μm and >1000 μm. Concentrations were calculated by soil volume (pieces cm^{-3}) and by accumulation rates (pieces cm^{-2} yr^{-1}) (Gavin et al., 2006; Higuera et al., 2009).

During enumeration, charcoal pieces were concomitantly categorised into morphotypes with a classification approach modified from Courtney Mustaphi and Pisaric (2014). Different morphologies of charcoal have different inertia that has to be overcome for entrainment, transport, and deposition in air or water (Whitlock and Larsen, 2001; Enache and Cumming, 2006; Scott, 2010; Hawthorne et al., 2018; Vachula and

Richter, 2018). The friction (or shear) velocity threshold and aerodynamic resistance are related to the morphology, mass and density of the charcoal pieces (Kok et al., 2014) and some pieces require relatively less or more energy for entrainment. To explore the potential of differences in entrainment energy, the observed charcoal morphotypes in the soil profile were grouped by how readily entrainable and transportable the fragments were by convection and advection during burning and post fire (Enache and Cumming, 2006; Feurdean, 2021) on a qualitative index scale of 1 to 5 (easily entrainable=1; readily=2; moderately=3; resistant=4; very resistant=5), irrespective of the size of the charcoal pieces . Classification by index value was relative amongst the charcoal morphotypes observed throughout the soil pit and reflected anecdotal observation of the entrainment and transport of individual charcoal fragments and observations by analysts reported in published literature (Umbanhowar and McGrath 1998; Lynch et al., 2004; Enache and Cumming, 2007; Scott, 2010; Feurdean, 2021; Vachula and Rehn, 2023). The relative abundances of morphotypes were calculated as a percentage of the total charcoal count for each sample (Courtney Mustaphi and Pisaric, 2014; Steinberga and Stivrins, 2021; Rehn et al., 2022) and the radiocarbon data were applied to calculate accumulation rates for each morphotype (Enache and Cumming, 2006, 2007, 2009; Moos and Cumming, 2012; Feurdean et al., 2017). Charcoal concentrations were calculated for the >250 µm fraction, the 125–250 µm, and the combined total fraction (>125 µm) and accumulation rates calculated with the interpolated age-depth model ages. Charcoal morphotype accumulation rates were also calculated for each morphotype concentration with the sediment accumulation rate.

3 RESULTS

3.1 Forest plot

The central and western side of Mount Lico contained a slightly drier forest with typical dry-to-mesic types of moist forest species, such as *Macaranga capensis* or *Newtonia buchananii* (Timberlake et al., 2019). The western forest plot had forest canopy tree species generally associated with miombo woodland, such as *Brachystegia spiciformis*, with evergreen forest taxa among the understory. The forest plot (20×20 m) around the soil pit contained 68 individual trees above 5 cm diameter breast height (dbh) comprising 11 different species, equivalent to 1700 stems per hectare and a plot basal area of 32.90 m^2 ha^{-1} (Table 1). At an 8 cm minimum dbh, the plot included nine species (*Chionanthus* and *Erythroxylum* were <8 cm dbh) with 32 stems, equalling 800 stems ha-1 and a relatively similar basal area equivalent to 30.2 m^2 ha^{-1}. Miombo taxon *B. spiciformis* was not found in other 20x20 m plots located toward the windward eastern part of Mount Lico, which mainly comprised moist forest tree species (Timberlake et al., 2019). The current forest composition and demographics (structure) of the western forests provides evidence of change in both structure and species composition over the past 200 to 50 years that may reflect hydroclimatic variability and different disturbance patterns (Timberlake et al., 2019).

3.2 Forest soil

The base of the soil pit was very poorly sorted muddy sands (loam) and the lowermost radiocarbon date calibrated to 7475 cal yr BP (Table S1, Figure 3) and a mean accumulation rate of 0.275 mm yr^{-1} (37 years cm^{-1}) that varied from 0.228–0.301 mm yr^{-1} (33–45 years cm^{-1}), as an estimate of stratigraphic accumulation that assumes limited vertical movement of the charcoal by mechanical or bioturbation processes (Figure S1). Overall, the profile face was a reddish-brown with massive to granular structure and a slight colour gradient at 100 cm and a brownish-black colouration in the uppermost 50–30 cm (Figures 2 and 3). Typical of tropical soils, the horizons diffuse into one another, visible by colour (Figure 2a–b and 3) and there were no conspicuous discontinuities in the profile and the radiocarbon ages were in sequence (Table S1). The thin leafy and very fine woody debris litter covered a thin O layer, and the A horizon had a variable transition depth across the pit face from 50–30 cm (Figure 3). Soil texture was upward fining from an average particle size of 375 µm with 50–85% sand to 30 µm with <50% sand and up to 80% clay in the uppermost soil (Figure 3), and contained some degraded fine plant remains and charcoal pieces (Figure 4a). Sand grains consisted commonly of rounded blocky reddish cemented aggregates, angular quartz and subangular magnetic mafic grains (Figure 4b and 4c). Dried soil bulk densities decreased consistently from ~1.10 g cm^{-3} at the base to 0.75 g cm^{-3} near the surface (Figure 3). Organic content (LOI 550 °C) at the base was approximately 8% and increased from 8–10% in the top 70 cm to a maximum of 15% at the surface. The deeper soils contained very little organic plant remains and charcoal (Figure 4c and 4d), which increased in the top 30 cm (Figure 3). Chitinous invertebrate remains were sporadic and infrequently observed with low concentrations , 0–2 pieces per 2 cm^{-3}, and were not identified.

3.3 Soil charcoal and past fires

Charcoal pieces were present throughout the entire profile and concentrations varied from 5–408 pieces cm^{-3} (median=28, σ=80 pieces cm^{-3}) and larger fragments >250 µm ranged 0–3 pieces cm^{-3} in the lower subzone and 0–4 pieces cm^{-3} in the uppermost metre (Figure 3).

. A total of 24 categories of charcoal morphotypes were enumerated throughout the profile (Table S2, Figure 5). Larger fragments were counted separately and a total of 42 charcoal pieces >250 μm were observed throughout the profile that were mostly morphotypes A1, A4 and B2a, which included 5 pieces >1000 μm (Figure 6). Only two morphotypes (A3 and B3) were found in every subsample and only 5 morphotypes (20.8%) occurred in over half of the samples and were the predominant morphotypes observed. Seventeen morphotypes (70.8%) occurred in ten samples or less. Blocky and polygonal morphotypes predominated and thin elongate charcoal pieces were relatively uncommon and rarely were counted from 50 cm depth to the top (past two millennia to present).

For a conservative interpretation of the entrainment and transport of sieved charcoal to the soil pit location, charcoal morphology entrainment index values of 1–3 were considered to be more easily transported and values and index values 4–5 were more local. For the entire record, the qualitative entrainable index sums had most charcoal, up to 80% relative abundances, in the relatively low entrainable energy (index values of 2 and 3) (Figure 7). Lower abundances of charcoal resistant to entrainment, which require more energy to transport, were found throughout the record and constituted up to 40% relative abundance from 7000–1500 cal BP (Figures 6 and 7). Very resistant to entrainment charcoal are more likely to be formed from fires local to the soil pit location (Figures 6 and S2). Since 1500 cal BP, the relative abundance of charcoal resistant to entrainment decreased to <10%; but, comparison of the relative abundances and accumulation rates (influx) show that the absolute amount of charcoal increased for all entrainment indices (Figure 6 compared with Figure 7). From 7000–1500 cal BP the influx of charcoal morphologies that were readily entrainable was minimal and much of the charcoal accumulation was made up of charcoal morphologies that were locally derived (Figure 7). The downcore profile shows large increases in both readily entrainable and resistant to entrainment morphotypes at the top of the profile, during the past <1500 cal BP. The influx of highly resistant charcoal morphotypes began to increase slightly prior to the peak charcoal influx (Figure 7). The relative abundance of readily entrainable morphotypes increase toward the top of the soil profile, while resistant to entrainment charcoal morphotypes relative abundances decrease (Figure 6), yet the accumulation rate of all for both highly entrainable and resistant both increase (Figure 7).

4 DISCUSSION

4.1 Modern forest, soil, and past ecological disturbances

The drier *Brachystegia* woodland and more mesic *Newtonia*- or *Macaranga*-dominated forests on Mount Lico are relatively depauperate floristically and more dense, in terms of number of stems per hectare, than many other forests across the southern African region. All plant taxa have relatively wide geographical distributions in southern Africa (Timberlake et al., 2019), although methods vary for assessments of forest structure and compositions around the region and comparisons between other forest plots in the region were not statistically tested. Mid-elevation forests of eastern Zimbabwe, although differing in composition from that on Mount Lico, have a basal area of around 46.6 m^2 ha^{-1} and a stem density around 536 stems ha^{-1} (Müller, 2006), while those from moist forests on Mount Mabu in northern Mozambique (Timberlake et al., 2012) had a basal area equivalent of 93.6 m^2 ha^{-1}. Results from Mount Lico are, however, more similar to those from semi-deciduous forest plots on the lower slopes of the Chimanimani Mountains in central Mozambique with a mean basal area of 31.4 m^2 ha^{-1} and a stem density of around 643 stems ha^{-1} (Timberlake et al., 2016; unpublished data; larger plot area and 8 cm dbh minimum size). Stem densities for woodland ("warm dry forests"), not moist forest, plots across southern Africa are around 700 to 800 per ha while basal area ranges from 11.5 to 14.1 m^2 ha^{-1} (Timberlake et al., 2010: 28), both values are lower than those recorded on Mount Lico.

The soil profile consisted of reddish soils with autochthonous weathered granitic rock and regional influx of dust that has accumulated on the gentle mountain top slope with an organic contribution of forest plant taxa. The sequence appeared unburied and polygenetic (Holliday et al., 2017) from weathered bedrock material, which was not reached during the dig, and organic input from the mountain forest, with the addition of abiotic and organic dust derived from the region. The B horizon was more sandy with the uppermost B from 90–50 cm being more clayey and transitioned in the more clay rich A horizon that was more brown and had a slightly higher organic content and much higher charcoal content (Figure 3). Other ferralitic soils derived from granite in Zimbabwe had comparable sand content (~60%) as Mount Lico (60–70%, Figure 3; Tomlinson, 1973, 1974). The analyses of the soil characteristics of Mount Lico provides additional insights on soil development in the absence of conspicuous direct anthropogenic modifications (Snijders, 1985; Stoorvogel and Smaling, 1990; Mercader et al., 2011) that cause erosion, nutrient changes, trampling, and affect seed banks (Folmer et al., 1998; Maria and Yost, 2006; Boles et al., 2019; Montfort et al., 2021). The most conspicuous changes in the soil profile were the increased organic content and charcoal content in the uppermost 30 cm, potentially the inconspicuous transition from a soil A horizon to a thin O horizon. The soil profile represents one of the few non-archaeological radiocarbon dated pedological datasets in eastern Africa since earlier work (Tomlinson, 1973: Tomlinson, 1974; Cooremans & Mahaney, 1990; Montade et al., 2018: Mekonnen et al., 2022). Other soil profile sites were radiometrically or stratigraphic date determinations (Wilkinson et al., 1986; Walling et al., 2003) or were not dated (Little and Lee, 2006; Lyu et al., 2021).

The increased clay content since the Mid-Holocene (~4200 cal BP) is notable and may be due to a change in local erosion or soil mineralogy. The upward fining is different from some other tropical soils where bioturbation can cause upward coarsened profiles (Zech et al., 2022). The increase may also be partly due to increased entrainment and transport of fine clastic material due to the combination of drier hydroclimatic conditions after the terminus of the African Humid Period (Thompson et al., 2002; Marchant and Hooghiesmtra, 2004; Shanahan et al., 2015) and from soil exposure to the atmosphere by land use changes of the surrounding lowlands that included pastoralism and agriculture (Figure 7). There is an increase in charcoal and clay content in the uppermost section, during the past two millennia (Figure 7), and may relate to increased fire activity and expansion of lowland forest conversion to relatively more open and intensively used agricultural landscapes.

Variations in fire disturbance patterns have strong effects on vegetation structure and compositions as well as effects on soil characteristics (Kobziar et al., 2024). The marked increase in charcoal concentration, the relative proportions of charcoal morphotypes, and the increased charcoal accumulation rate, suggest important changes to the fire ecology on and near Mount Lico during the past millennium. The increased charcoal and morphology assemblage interpretation could be due to more local (mountain top) and extralocal burning (lowlands), yet direct causal links cannot be drawn without further evidence. Charcoal was found in all samples analysed throughout the entire profile. Local biomass burning at the location of the soil pit appears to have been moderately high during the Mid Holocene and lowest around the Late-to-Mid Holocene transition, concomitant with increased clay content (Figure 7). The larger charcoal pieces , >250 μm, more likely to be deposited from local fires (Blackford, 2000; Oris et al., 2014), are more common in the soil pit from Late Holocene and again during the past two millennia (Figure 6). Charcoal content has increased during the past two millannia, concomitant with increased reconstructed annual temperatures and lowest precipitation in the wettest quarter (of the year) in southern Africa (Figure 7; Chase et al., 2017). Fire is a factor influencing the modern tree composition and forest structure (Timberlake et al., 2019) and the peak charcoal content within the past 1000 years and slight decrease to the soil surface suggest this is true for the past millennium. The persistent occurrence throughout the record of both readily entrainable and highly resistant to entrainment suggests that fires have occurred at both the extralocal-to-regional scale (lowland) and the local mountaintop (Figure 7). The relative abundance of morphotypes resistant to entrainment suggests that much more readily entrainable charcoal was accumulating at the Mount Lico soil pit during the past 1500 cal BP and that local highland burning on Mount Lico also increased. The increased fires on top of Mount Lico could be due to increased fire weather conditions and ignitions from lowland fire brands, lightning, spontaneous ignitions, or anthropogenic ignitions. Charcoal production has been shown to increase soil organic carbon content and total nitrogen in abandoned kilns in dry forest areas of southern Mozambique (Lisboa et al., 2020), and anthropogenic fire use have modified soils in other forests of eastern Africa (Glaser et al., 2001; Gil-Romera et al., 2019; Ossendorf et al., 2019) and in other parts of the world (Glaser et al., 2000; Maezumi et al., 2022). In the absence of further evidence, it remains uncertain to disentangle the relative importance of anthropogenic or environmental drivers of the changed fire regime (Razanatsoa et al., 2022). Interdisciplinary research on paleoenvironments, archaeology, anthropology, and oral traditions would help understand the drivers of environmental change of the mountain over the past ~2000 years (Shetler, 2007; Armstrong et al., 2017; Courtney Mustaphi et al., 2019; Odonne and Molino, 2020; Lane et al., 2024).

The entrainability index presents a qualitative exploration of the charcoal morphology data and could be refined with experimental and modelling data, with comparison to environmental data of charcoal production, entrainment, transport, and deposition (Pisaric, 2002; Scott, 2010; Courtney Mustaphi and Pisaric, 2014; Hawthorne et al., 2018; Courtney Mustaphi et al., 2021b, 2022). Numerical approaches and field-based observations of charcoal related to paleofire literature have focused on charcoal source area, transport and deposition (Clark, 1988; Higuera et al., 2007; Peters and Higuera, 2007; Vachula and Richter, 2018; Vachula, 2021) and further exploration of charcoal entrainment (friction velocity) of different charcoal particle sizes and morphotypes would refine these approaches (Wagenbrenner et al., 2013; Mueller et al., 2015; Wagenbrenner et al., 2017; Li et al., 2018) and fluxes of charcoal from lowlands to highland landscape features (Butler et al., 2015; Vachula et al., 2018; Courtney Mustaphi et al., 2021b, 2022, 2023).

4.2 Regional comparisons

There appears to have been limited direct forest and soil modifications by humans in the past atop Mount Lico owing to extreme inaccessibility and parts of the mountain forest have been modified by fire. Human livelihood strategies across southeastern Africa included hunter-gatherer, subsistence agriculture, pastoralism, and Neolithic and Iron Age agriculture throughout the past 8000 years and increasingly modified vegetation (Figure 7). Ceramic evidence suggests connectivity of the region with eastern africa in the past 3000 years (Lane, 2004; Barham and Mitchell, 2008) and coastal trade with Madagascar and other islands demonstrate the trade connectivity and exchange within the western Indian Ocean region and potential for influencing changing land use patterns since the later first millennium (Morais, 1984; Sinclair et al., 2012; Boivin et al., 2013; Ekblom et al., 2016). Archaeological evidence suggests agriculture along internal permanent rivers in southeastern Africa by 800 CE (1200 cal BP) (Morais, 1984; Ekblom et al., 2011). Further archaeological investigations on the mountain are required to further verify the degree of human occupation on the isolated mountain and syntheses of past land uses of interior Mozambique. Broadly, investigations of Holocene sediment-charcoal morphotypes show that assemblages changes through time have been associated with known climate changes (Enache and Cumming, 2007; Courtney Mustaphi and Pisaric, 2014) and land use changes (Cheung et al., 2021; Frank-DePue et al., 2023). Further analyses are required to understand the relative importance of different fire regime variables on the charcoal morphotype assemblage at a local site scale (Courtney Mustaphi and Pisaric, 2018).

4.3 Outlook on future research

The soil profile of Mount Lico shows some of the potential and challenges for analysing paleoenvironmental proxies from tropical soils to interpret vegetation change at extra local to local scales. Further analyses of inaccessible isolated woodland forests offer a natural experiment for tropical tree-grass-disturbance dynamics (Gambiza et al., 2000; Timberlake et al., 2019; Donaldson et al., 2022; Holdo et al., 2022); notably where herbivory pressures by mammals are low, and coupled with analyses of soil, wetland, and lacustrine geoarchives to examine these ecological interactions over centennial to millennial time scales (Turner et al., 2003; Newman, 2019; Napier and Chipman, 2021). Further work on laboratory and field-based experiments that generate charcoal morphotypes from known fuels and fire conditions (Belcher et al., 2005; Maezumi et al., 2021) would permit the differentiation of source areas for charcoal pieces >125 µm, notably in isolated highland deposits, or in small watersheds. Analysis of taphonomic processes in soils that include bioturbation, soil creep, wetting and drying cycles, (sub)fossil taphonomy and the resulting effects on paleoenvironmental interpretations has yet to be a focal topic in tropical ecosystems and would improve proxy methods and interpretability of results. The use of the radiocarbon dated charcoal assumes that there has been limited vertical movement of the charcoal in the soil sequence and future research on the taphonomic behaviour of charcoal and organic matter in tropical soils would be useful to understand the influences of wetting and drying cycles and bioturbation by animals, plants and fungi.

Charcoal morphology assemblages as a signal of charcoal formation, entrainment, transport and deposition would benefit from further numerical and experimental development, as it is known that both charcoal particle size, shape, and density interact and contribute to the paleoenvironmental signal (Higuera et al., 2007) as well as wind and water transport and surface conditions (Vos et al., 2020; Courtney Mustaphi et al., 2022) and taxon identifications (Hubau et al., 2013; Scheel-Ybert, 2016). Future research could make use of other fossil vegetation evidence from phytoliths (Courtney Mustaphi et al. 2021b), pollen and and macrobotanical remains (Mworia-Maitima, 1997; Wooller, 2002; Olatoyan et al., 2022), biomarkers, and geochronological and taphonomic studies (Uno et al., 2016). Improved and more refined interpretation will arise from a combination of the results of this study with geomorphological and soil catena data from isolated highlands, additional radionuclide geochronological techniques, and additional proxy paleoindicator data.

5. CONCLUSIONS

The palaeoenvironmental record of the soil pit on Mount Lico over the past 8000 years shows some sensitivity to regional paleoclimate and potentially human land use changes over the past <1500 cal BP. Modern forest observations from Mount Lico provide evidence of fine spatial scale variations of more mesic and drier forest types, driven by the relative importance of geomorphological, hydroclimatic, and disturbance ecology dynamics, potentially at multidecadal to centennial scales. The soil texture and charcoal data suggest local and regional vegetation changes in response to the hydroclimate regime during the Late-to-Mid Holocene transition and ending of the African Humid Period. Changes to the fire regime is evident over the past 1500 cal BP with more biomass burning in both the lowlands and locally on the highland. The categorisation of charcoal morphotypes, and potentially co-assigned size fractions, shows some potential to add insights to palaeofire records and further quantification studies will improve the approaches used here. The charcoal morphology and qualitative index of entrainment and transport is a novel technique that could be applied to other environmental settings with physical barriers to local and extralocal source areas. The results show the potential for tropical soils to be used as geoarchives of past vegetation changes, especially in locations with few permanent water bodies that accumulate sediments. Such insights, in addition to improving our ability to reconstruct past human ecosystem environment interactions, can provide new insights to inform the conservation of these systems in a rapidly changing world.

AUTHOR CONTRIBUTIONS

PP SW JT JO HM HSO JB organised and participated in fieldwork. Surveying and sample collection by PP SW JT JO. CCM PP SW RM conceived this study. CCM MG collected and analysed the data. All authors contributed to the writing of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary information of this article and from the following repository.

or

Data citation:

[dataset] Courtney Mustaphi, C; 2024; "Soil pit data for "Tree demographics and soil charcoal evidence of fire disturbances in an inaccessible forest atop the Mount Lico inselberg, Mozambique"; Harvard Dataverse; version 1; https://doi.org/10.7910/DVN/EZIWDT

*The authors plan to make this data available through multiple channels, including open access Neotoma repository that gives the data a DOI and the Global Charcoal Database. This can be cross referenced with the publication upon acceptance by the journal.

REFERENCES

Abbott. P., & Ruggeri, R. (2002). *Armies in East Africa 1914-18*. Oxford, Osprey.

Allan, J.R., Grossmann, F., Craig, R., Nelson, A., Maina, J., Flower, K., Bampton, J., Deffontaines, J.B., Miguel, C., Araquechande, B., & Watson, J.E., Allan, J.R., Grossmann, F., Craig, R., et al. (2017). Patterns of forest loss in one of Africa's last remaining wilderness areas: Niassa National Reserve (northern Mozambique). *Parks*, 23(2), 39–50.

Archibald, S., Staver, A.C. & Levin, S.A. (2012). Evolution of human-driven fire regimes in Africa. Proceedings of the National Academy of Sciences, 109(3), 847–852.

Bamber, R.N. (1982). Sodium hexametaphosphate as an aid in benthic sample sorting. *Marine Environmental Research*, 7(4), 251–255.

Barbee, J. (2018) Mozambique: the secret rainforest at the heart of an African volcano. A 'dream team' of scientists scaled Mount Lico and found a wealth of new species. The Guardian, 17 June 2018. Available: https://www.theguardian.com/world/2018/jun/17/mozambique-mount-lico-rainforest-new-species last accessed 20 May 2024.

Barham, L., & Mitchell, P. (2008). *The First Africans: African Archaeology from the earliest toolmakers to most recent foragers*. Cambridge, UK: Cambridge University Press.

Bayliss, J., Timberlake, J., Branch, W., Bruessow, C., Collins, S., Congdon, C., Curran, M., De Sousa, C., Dowsett, R., Dowsett-Lemaire, F., & Fishpool, L. (2014). The discovery, biodiversity and conservation of Mabu forest—the largest medium-altitude rainforest in southern Africa. *Oryx*, 48(2), 177–185.

Bayliss, J.L., Congdon, T.C.E., Richardson, I.D., & Collins, S.C. (2022). Revision of the *A. delicata* group of *Afriodinia* d'Abrera, 2009 (Papilionoidea: Riodinidae) with the description of a new species from Mount Lico, Northern Mozambique, and the reinstatement of a species. *Metamorphosis*, 33, 35–42.

Bayliss, J., Bittencourt-Silva, G.B., Branch, W.R., Bruessow, C., Collins, S., Congdon, T.C.E., Conradie, W., Curran, M., Daniels, S.R., Darbyshire, I., & Farooq, H. (2024). A biogeographical appraisal of the threatened South East Africa Montane Archipelago ecoregion. *Scientific Reports*, 14(1), 5971.

Belcher, C.M., Collinson, M.E., & Scott, A.C. (2005). Constraints on the thermal energy released from the Chicxulub impactor: new evidence from multi-method charcoal analysis. *Journal of the Geological Society*, 162(4), 591–602.

Bittencourt-Silva, G.B., Bayliss, J., & Conradie, W. (2020). First herpetological surveys of Mount Lico and Mount Socone, Mozambique. *Amphibian & Reptile Conservation*, 14(2), 198–217.

Blackford, J.J. (2000). Charcoal fragments in surface samples following a fire and the implications for interpretation of subfossil charcoal data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 164(1–4), 33–42.

Blaauw, M. (2010) Methods and code for 'classical' age-modelling of radiocarbon sequences. *Quaternary Geochronology,* 5(5), 512–518.

Blott, S.J., & Pye, K. (2001). GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. *Earth Surface Processes and Landforms,* 26(11), 1237–1248.

Boivin, N., Crowther, A., Helm, R., & Fuller, D.Q. (2013). East Africa and Madagascar in the Indian ocean world. *Journal of World Prehistory*, 26(3), 213–281.

Boles, O.J., Shoemaker, A., Courtney Mustaphi, C.J., Petek, N., Ekblom, A., & Lane, P.J. (2019). Historical ecologies of pastoralist overgrazing in Kenya: long-term perspectives on cause and effect. *Human Ecology*, 47(3), 419–434.

Bower, J.R.F. (1973). Seronera: excavations at a stone bowl site in the Serengeti National Park, Tanzania. *Azania*, 8, 71–104.

Bower, J., & Chadderdon, T.J. (1986). Further excavations of Pastoral Neolithic sites in Serengeti. *Azania*, 21(1), 129–133.

Burgess, N., Hales, J.A., Underwood, E., Dinerstein, E., Olson, D., Itoua, I., Schipper, J., Ricketts, T., & Newman, K. (2004). *Terrestrial ecoregions of Africa and Madagascar: a conservation assessment*. Washington DC, USA: Island Press.

Burgess, N.D., Balmford, A., Cordeiro, N.J., Fjeldså, J., Kueper, W., Rahbek, C., Sanderson, E.W., Scharlemann, J.P., Sommer, J.H., & Williams, P.H. (2007). Correlations among species distributions, human density and human infrastructure across the high biodiversity tropical mountains of Africa. *Biological Conservation*, 134(2), 164–177.

Burrows, J.E., Burrows, S., Schmidt, E., Lotter, M., & Wilson, E.O. (2018). *Trees and shrubs Mozambique*. Cape Town, South Africa: Print Matters Heritage. 1114p.

Butler, B.W., Wagenbrenner, N.S., Forthofer, J.M., Lamb, B.K., Shannon, K.S., Finn, D., Eckman, R.M., Clawson, K., Bradshaw, L., Sopko, P., & Beard, S. (2015). High-resolution observations of the near-surface wind field over an isolated mountain and in a steep river canyon. *Atmospheric Chemistry and Physics*, 15(7), 3785–3801.

Calabrese, J.A. (2000). Interregional interaction in southern Africa: Zhizo and Leopard's Kopje relations in northern South Africa, southwestern Zimbabwe, and eastern Botswana, AD 1000 to 1200. *African Archaeological Review*, 17, 183–210.

Chami, F., & Ntandu, C. (2018). Eastern Africa in classical times. In: Ekblom, A., Graham, E., & Isendahl, C. (eds) The Resilience of Heritage: Cultivating a Future of the Past. Essays in Honour of Professor Paul JJ Sinclair. Studies in Global Archaeology 23. Uppsala University, Sweden. pp.291–305.

Chase, B.M., Chevalier, M., Boom, A., & Carr, A.S. (2017). The dynamic relationship between temperate and tropical circulation systems across South Africa since the last glacial maximum. *Quaternary Science Reviews*, 174, 54–62.

Cheung, A.H., Vachula, R.S., Clifton, E., Sandwick, S., & Russell, J.M., (2021). Humans dominated biomass burning variations in Equatorial Asia over the past 200 years: Evidence from a lake sediment charcoal record. *Quaternary Science Reviews*, 253, 106778.

Clark, J.S. (1988). Particle motion and the theory of charcoal analysis: source area, transport, deposition, and sampling. *Quaternary Research*, 30(1), 67–80.

Conradie, W., Bittencourt-Silva, G., Engelbrecht, H.M., Loader, S.P., Menegon, M., Nanvonamuquitxo, C., Scott, M., & Tolley, K.A. (2016). Exploration into the hidden world of Mozambique's sky island forests: new discoveries of reptiles and amphibians. *Zoosystematics and Evolution*, 92(2), 163–180.

Cooremans, B., & Mahaney, W.C. (1990). Palynology of a Quaternary paleosol sequence on Mount KE, East Africa. *Palaeoecology of Africa*, 21, 283–294.

Courtney Mustaphi, C.J., & Pisaric, M.F.J. (2014). A classification for macroscopic charcoal morphologies found in Holocene lacustrine sediments. *Progress in Physical Geography*, 38, 734–754.

Courtney Mustaphi, C.J., & Pisaric, M.F.J. (2018). Forest vegetation change and disturbance interactions over the past 7500 years at Sasquatch Lake, Columbia Mountains, western Canada. *Quaternary International*, 488, 95–106.

Courtney Mustaphi, C.J., Capitani, C., Boles, O., Kariuki, R., Newman, R., Munishi, L., Marchant, R., & Lane, P. (2019). Integrating evidence of land use and land cover change for land management policy formulation along the Kenya-Tanzania borderlands. *Anthropocene*, 28, 100228.

Courtney-Mustaphi, C., Kariuki, R., Shoemaker, A., Munishi, L., Ekblom, A., Marchant, R., & Lane, P. (2021a). Understanding land use and land cover changes in northern Tanzania. *Swiss Society for African Studies SSAS newsletter*, 2021/1, 20–23.

Courtney Mustaphi, C.J., Kinyanjui, R., Shoemaker, A., Mumbi, C., Muiruri, V., Marchant, L., Rucina, S.M., & Marchant, R. (2021b). A 3000-year record of vegetation changes and fire at a high-elevation wetland on Kilimanjaro, Tanzania. *Quaternary Research*, 99, 34–62.

Courtney Mustaphi, C.J., Vos, H.C., Marchant, R., & Beale, C. (2022). Charcoal whirlwinds and post-fire observations in Serengeti National Park savannahs. *Tanzania Journal of Science*, 48(2), 460–473.

Courtney Mustaphi, C.J., Rucina, S., & Marchant, R. (2023). Late Pleistocene montane forest fire return interval estimates from Mount Kenya. *Journal of Quaternary Science*, 38(2), 146–159.

Daniels, S.R., Bittencourt-Silva, G.B., Muianga, V., & Bayliss, J. (2020). Phylogenetics of the freshwater crab (Potamonautes MacLeay, 1838) fauna from ‘sky islands’ in Mozambique with the description of a new species (Brachyura: Potamoidea: Potamonautidae). *European Journal of Taxonomy*, 716, 1–23.

Darbyshire, I., Timberlake, J., Osborne, J., Rokni, S., Matimele, H., Langa, C., Datizua, C., de Sousa, C., Alves, T., Massingue, A., & Hadj-Hammou, J. (2019). The endemic plants of Mozambique: diversity and conservation status. *PhytoKeys*, 136, 45–96.

Donaldson, J.E., Holdo, R., Sarakikya, J., & Anderson, T.M. (2022). Fire, grazers, and browsers interact with grass competition to determine tree establishment in an African savanna. *Ecology*, 103(8), e3715.

Ekblom, A. (2012). Livelihood security, vulnerability and resilience: a historical analysis of Chibuene, Southern Mozambique. *Ambio*, 41(5), 479–489.

Ekblom, A. (2018). *An historical ecology of cattle in Mozambique*. Oxford University Press.

Ekblom, A., Gillson, L., & Notelid, M. (2011). A historical ecology of the Limpopo and Kruger National Parks and Lower Limpopo Valley. *Journal of Archaeology and Ancient History*, 1(1), 1–29.

Ekblom, A., Eichhorn, B., Sinclair, P., Badenhorst, S. & Berger, A. (2014). Land use history and resource utilisation from A.D. 400 to the present, at Chibuene, southern Mozambique. *Vegetation History and Archaeobotany*, 23, 15–32.

Ekblom, A., Lane, P., Radimilahy, C., Rakotoarisoa, J.A., Sinclair, P., & Virah-Sawmy, M. (2016). Migration and interaction between Madagascar and Eastern Africa, 500 BCE–1000

CE: an archaeological perspective. In: Campbell, G. (ed), *Early Exchange between Africa and the wider Indian Ocean world*. Cham: Palgrave Macmillan, pp.195–230.

Enache, M.D., & Cumming, B.F. (2006). Tracking recorded fires using charcoal morphology from the sedimentary sequence of Prosser Lake, British Columbia (Canada). *Quaternary Research*, 65(02), 282–292.

Enache, M.D., & Cumming, B.F. (2007). Charcoal morphotypes in lake sediments from British Columbia (Canada): an assessment of their utility for the reconstruction of past fire and precipitation. *Journal of Paleolimnology*, 38(3), 347–363.

Enache, M.D., & Cumming, B.F. (2009). Extreme fires under warmer and drier conditions inferred from sedimentary charcoal morphotypes from Opatcho Lake, central British Columbia, Canada. *The Holocene*, 19(6), 835–846.

Feurdean, A., Veski, S., Florescu, G., Vannière, B., Pfeiffer, M., O'Hara, R.B., Stivrins, N., Amon, L., Heinsalu, A., Vassiljev, J., & Hickler, T. (2017). Broadleaf deciduous forest counterbalanced the direct effect of climate on Holocene fire regime in hemiboreal/boreal region (NE Europe). *Quaternary Science Reviews*, 169, 378–390.

Feurdean, A. (2021). Experimental production of charcoal morphologies to discriminate fuel source and fire type: an example from Siberian taiga. *Biogeosciences*, 18(12), 3805–3821.

Finch, J., Wooller, M., & Marchant, R. (2014). Tracing long-term tropical montane ecosystem change in the Eastern Arc Mountains of Tanzania. *Journal of Quaternary Science*, 29(3), 269–278.

Fleisher, J., Lane, P., LaViolette, A., Horton, M., Pollard, E., Quintana Morales, E., Vernet, T., Christie, A., & Wynne-Jones, S. (2015). When did the Swahili become maritime? *American Anthropologist*, 117(1), 100–115.

Folmer, E.C.R., Geurts, P.M.H., & Francisco, J.R. (1998). Assessment of soil fertility depletion in Mozambique. *Agriculture, Ecosystems & Environment*, 71(1–3), 159–167.

Frank-DePue, L., Vachula, R.S., Balascio, N.L., Cahoon, K., & Kaste, J.M. (2023). Trends in sedimentary charcoal shapes correspond with broad-scale land-use changes: insights gained from a 300-year lake sediment record from eastern Virginia, USA. *Journal of Paleolimnology*, 69, 21–36.

Gambiza, J., Bond, W., Frost, P.G.H., Higgins, S. (2000). A simulation model of miombo woodland dynamics under different management regimes. *Ecological Economics*, 33(3), 353–368.

Gavin, D.G., Hu, F.S., Lertzman, K., & Corbett, P. (2006). Weak climatic control of stand-scale fire history during the late Holocene. *Ecology*, 87(7), 1722–1732.

Gil-Romera, G., Adolf, C., Benito, B.M., Bittner, L., Johansson, M.U., Grady, D.A., Lamb, H.F., Lemma, B., Fekadu, M., Glaser, B., & Mekonnen, B. (2019). Long-term fire resilience of the Ericaceous Belt, Bale Mountains, Ethiopia. *Biology Letters*, 15(7), 20190357.

Githumbi, E.N., Courtney Mustaphi, C.J., & Marchant, R. (2021). Late Pleistocene and Holocene Afromontane vegetation and headwater wetland dynamics within the Eastern Mau Forest, Kenya. *Journal of Quaternary Science*, 36(2), 239–254.

Glaser, B., Balashov, E., Haumaier, L., Guggenberger, G., & Zech, W. (2000). Black carbon in density fractions of anthropogenic soils of the Brazilian Amazon region. *Organic Geochemistry*, 31(7–8), 669–678.

Glaser, B., Lehmann, J., Führböter, M., Solomon, D., & Zech, W. (2001). Carbon and nitrogen mineralization in cultivated and natural savanna soils of Northern Tanzania. *Biology and Fertility of Soils*, 33, 301–309.

Hawthorne, D., Courtney Mustaphi, C.J., Aleman, J.C., Blarquez, O., Colombaroli, D., Daniau, A.-L., Marlon, J.R., Power, M., Vanniere, B., Han, Y., Hantson, S., Kehrwald, N., Magi, B., Yue, X., Carcaillet, C., Marchant, R., Ogunkoya, A., Githumbi, E.N., Muriuki, R.M. (2018). Global Modern Charcoal Dataset (GMCD): a tool for exploring proxy-fire linkages and spatial patterns of biomass burning. *Quaternary International*, 488, 3–17.

Heckmann, M. (2014). Farmers, smelters and caravans: two thousand years of land use and soil erosion in North Pare, NE Tanzania. *Catena*, 113, 187–201.

Heiri, O., Lotter, A.F. & Lemcke, G. (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of Paleolimnology*, 25, 101–110.

Higuera, P.E., Peters, M.E., Brubaker, L.B., & Gavin, D.G. (2007). Understanding the origin and analysis of sediment-charcoal records with a simulation model. *Quaternary Science Reviews*, 26(13–14), 1790–1809.

Higuera, P.E., Brubaker, L.B., Anderson, P.M., Hu, F.S., & Brown, T.A. (2009). Vegetation mediated the impacts of postglacial climate change on fire regimes in the south-central Brooks Range, Alaska. *Ecological Monographs*, 79(2), 201–219.

Hogg, A.G., Heaton, T.J., Hua, Q., et al. (2020). SHCal20 Southern Hemisphere calibration, 0–55,000 years cal BP. *Radiocarbon*, 62(4), 759–778.

Holdo, R.M., Donaldson, J.E., Rugemalila, D.M., et al. (2022). Sapling growth gradients interact with homogeneous disturbance regimes to explain savanna tree cover discontinuities. *Ecological Monographs*, 92(3), e1514.

Holliday, V.T., Mandel, R.D., & Beach, T. (2017). Soil Stratigraphy. In: Gilbert, A.S. (eds) *Encyclopedia of Geoarchaeology. Encyclopedia of Earth Sciences Series*. Springer, Dordrecht. pp.841–855. https://doi.org/10.1007/978-1-4020-4409-0_177

Hubau, W., Van den Bulcke, J., Kitin, P., Mees, F., Baert, G., Verschuren, D., Nsenga, L., Van Acker, J., Beeckman, H. (2013). Ancient charcoal as a natural archive for paleofire regime and vegetation change in the Mayumbe, Democratic Republic of the Congo. *Quaternary Research*, 80(2), 326–340.

Ichumbaki, E.B., & Pollard, E. (2021). The Swahili Civilization in Eastern Africa. In *Oxford Research Encyclopedia of Anthropology*. Oxford, UK: Oxford University Press. https://doi.org/10.1093/acrefore/9780190854584.013.267

Instituto Nacional de Geologia (1987). *Carta geológica scale 1:1,000,000* [map]. Maputo, Mozambique: Instituto Nacional de Geologia.

Jones, S.E.I., Clause, J.K., Geeraert, L., Jamie, G.A., Sumbane, E., Van Berkel, T., & Jocque, M. (2017). *The Njesi Plateau expedition: a biological assessment of Mt Chitagal, Mt Sanga and the Njesi Plateau in Niassa Province, Mozambique*. BES Report 6.3. Glabbeek, Belgium: Biodiversity Inventory for Conservation.

Kobziar, L.N., Hiers, J.K., Belcher, C.M., Bond, W.J., Enquist, C.A., Loudermilk, E.L., Miesel, J.R., O'Brien, J.J., Pausas, J.G., Hood, S., & Keane, R. (2024). Principles of fire ecology. *Fire Ecology*, 20, 39.

Kok, J.F., Mahowald, N.M., Fratini, G., Gillies, J.A., Ishizuka, M., Leys, J.F., Mikami, M., Park, M.S., Park, S.U., Van Pelt, R.S., & Zobeck, T.M. (2014). An improved dust emission model–Part 1: Model description and comparison against measurements. *Atmospheric Chemistry and Physics*, 14(23), 13023–13041.

Lane, P. (2004). The “Moving Frontier" and the transition to food production in Kenya. *Azania*, 39(1), 243–264.

Lane, P., Madry, S., & Jones, E. (2024). Landscape archaeology. In: Madry S, Westin A, Jones E (eds) Practising historical ecology methods for the collection, analysis, and integration of interdisciplinary historical data. SLU Swedish Biodiversity Centre, Swedish University of Agricultural Sciences, Uppsala, Sweden. pp.193–229.

Li, C., Bair, D.A., & Parikh, S.J. (2018). Estimating potential dust emissions from biochar amended soils under simulated tillage. *Science of the Total Environment*, 625, 1093–1101.

Little, M.G., & Lee, C.T.A. (2006). On the formation of an inverted weathering profile on Mount Kilimanjaro, Tanzania: Buried paleosol or groundwater weathering? *Chemical Geology*, 235(3–4), 205–221.

Lisboa, S.N., Woollen, E., Grundy, I.M., Ryan, C.M., Smith, H.E., Zorrilla-Miras, P., Baumert, S., Ribeiro, N., Vollmer, F., Holland, M., & Sitoe, A. (2020). Effect of charcoal production and woodland type on soil organic carbon and total nitrogen in drylands of southern Mozambique. *Forest Ecology and Management*, 457, 117692.

Lyu, H., Watanabe, T., Sugimoto, S., Kilasara, M., & Funakawa, S. (2021). Control of climate on soil charge characteristics through organic matter and clay mineral distributions in volcanic soils of Mt. Kilimanjaro, Tanzania. *Soil Science and Plant Nutrition*, 67(3), 288–300.

Lynch, J.A., Clark, J.S., & Stocks, B.J. (2004). Charcoal production, dispersal, and deposition from the Fort Providence experimental fire: interpreting fire regimes from charcoal records in boreal forests. *Canadian Journal of Forest Research*, 34(8), 1642–1656.

Maezumi, S.Y., Gosling, W.D., Kirschner, J., Chevalier, M., Cornelissen, H.L., Heinecke, T., & McMichael, C.N. (2021). A modern analogue matching approach to characterize fire temperatures and plant species from charcoal. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 578, 110580.

Maezumi, S.Y., Elliott, S., Robinson, M., Betancourt, C.J., Gregorio de Souza, J., Alves, D., Grosvenor, M., Hilbert, L., Urrego, D.H., Gosling, W.D., & Iriarte, J. (2022). Legacies of Indigenous land use and cultural burning in the Bolivian Amazon rainforest ecotone. *Philosophical Transactions of the Royal Society B*, 377(1849), 20200499.

Marchant, R. & Hooghiemstra, H. (2004). Rapid environmental change in African and South American tropics around 4000 years before present: a review. *Earth-Science Reviews*, 66(3–4), 217–260.

Marchant, R., Richer, S., Boles, O., et al. (2018). Drivers and trajectories of land cover change in East Africa: human and environmental interactions from 6000 years ago to present. *Earth-Science Reviews*, 178, 322–378.

Maria, R.M., & Yost, R. (2006). A survey of soil fertility status of four agroecological zones of Mozambique. *Soil Science*, 171(11), 902–914.

McLachlan, A.J. (1988). Refugia and habitat partitioning among midges (Diptera: Chironomidae) in rain-pools. *Ecological Entomology*, 13(2), 185–193.

McLachlan, A.J., & Cantrell, M.A. (1980). Survival strategies in tropical rain pools. *Oecologia*, 47(3), 344–351.

McLachlan, A.J., & Ladle, R.J. (2009). The evolutionary ecology of detritus feeding in the larvae of freshwater Diptera. *Biological Reviews*, 84(1), 133–141.

Mekonnen, B., Glaser, B., Zech, R., Zech, M., Schlütz, F., Bussert, R., Addis, A., Gil-Romera, G., Nemomissa, S., Bekele, T., & Bittner, L. (2022). Climate, vegetation and fire history during the past 18,000 years, recorded in high altitude lacustrine sediments on the Sanetti Plateau, Bale Mountains (Ethiopia). *Progress in Earth and Planetary Science*, 9, 14.

Mercader, J., Bennett, T., Esselmont, C., Simpson, S., & Walde, D. (2011). Soil phytoliths from miombo woodlands in Mozambique. *Quaternary Research*, 75(1), 138–150.

Miller, C. (1974). *Battle for the Bundu: The First World War in East Africa*. New York, USA: Macmillan Publishing.

Migoń, P., Duszyński, F., & Goudie, A. (2017). Rock cities and ruiniform relief: Forms–processes–terminology. *Earth-Science Reviews*, 171, 78–104.

Montade, V., Schüler, L., Hemp, A., Bremond, L., Salamanca Duarte, A.M., & Behling, H. (2018). Late Quaternary ecotone change between sub-alpine and montane forest zone on the leeward northern slope of Mt. Kilimanjaro. *Journal of Vegetation Science*, 29(3), 459–468.

Montfort, F., Nourtier, M., Grinand, C., Maneau, S., Mercier, C., Roelens, J.B., & Blanc, L. (2021). Regeneration capacities of woody species biodiversity and soil properties in Miombo woodland after slash-and-burn agriculture in Mozambique. *Forest Ecology and Management*, 488, 119039.

Moos, M.T., & Cumming, B.F. (2012). Climate–fire interactions during the Holocene: a test of the utility of charcoal morphotypes in a sediment core from the boreal region of north-western Ontario (Canada). *International Journal of Wildland Fire*, 21(6), 640–652.

Morais, J.M. (1984). Mozambican archaeology: past and present. *African Archaeological Review*, 2, 113–128.

Müller, T. (2006). *The distribution, classification and conservation of rainforests in Eastern Zimbabwe*. Occasional Publications in Biodiversity No.19. Biodiversity Foundation for Africa Bulawayo, Zimbabwe.

Mueller, S.F., Mallard, J.W., Mao, Q., & Shaw, S.L. (2015). Variability of natural dust erosion from a coal pile. *Journal of Applied Meteorology and Climatology*, 54(1), 3–14.

Mworia-Maitima, J. (1997). Prehistoric fires and land-cover change in western Kenya: evidences from pollen, charcoal, grass cuticles and grass phytoliths. *The Holocene*, 7(4), 409–417.

Napier, J.D., & Chipman, M.L. (2022). Emerging palaeoecological frameworks for elucidating plant dynamics in response to fire and other disturbance. *Global Ecology and Biogeography*, 31(1), 138–154.

National Geographic, 2020. The Lost Forest | Nobel Peace Prize Shorts [digital video]. 22 May 2020. Duration 21m 54s.
Available at https://youtu.be/aDoanNM7O_s last accessed 17 June 2024.

Newman, E.A. (2019). Disturbance ecology in the Anthropocene. *Frontiers in Ecology and Evolution*, 7, 147.

Nurse, D., & Spear, T. (1985). *The Swahili: Reconstructing the history and language of an African society, 800-1500*. University of Pennsylvania Press.

Odonne, G., & Molino, J.F. (Eds.). (2020). *Methods in historical ecology: insights from Amazonia*. Routledge.

Olatoyan, J.O., Neumann, F.H., Orijemie, E.A., Sievers, C., Evans, M., Mvelase, S., Hattingh, T., & Schoeman, M.H. (2022). Archaeobotanical evidence for the emergence of pastoralism and farming in southern Africa. *Acta Palaeobotanica*, 62(1), 50–75.

Oris, F., Ali, A.A., Asselin, H., Paradis, L., Bergeron, Y., & Finsinger, W. (2014). Charcoal dispersion and deposition in boreal lakes from 3 years of monitoring: differences between local and regional fires. *Geophysical Research Letters*, 41(19), 6743–6752.

Ossendorf, G., Groos, A.R., Bromm, T., Tekelemariam, M.G., Glaser, B., Lesur, J., Schmidt, J., Akçar, N., Bekele, T., Beldados, A., Demissew, S. (2019). Middle Stone Age foragers resided in high elevations of the glaciated Bale Mountains, Ethiopia. *Science*, 365(6453), 583–587.

Peters, M.E., & Higuera, P.E. (2007). Quantifying the source area of macroscopic charcoal with a particle dispersal model. *Quaternary Research*, 67(2), 304–310.

Pisaric, M.F. (2002). Long-distance transport of terrestrial plant material by convection resulting from forest fires. *Journal of Paleolimnology*, 28(3), 349–354.

R Development Core Team (2021). R version 4.1.2 (2021-11-01) "Bird Hippie" 64bit. Vienna, Austria: The R Foundation for Statistical Computing.

Razanatsoa, E., Gillson, L., Virah-Sawmy, M., & Woodborne, S. (2022). Synergy between climate and human land-use maintained open vegetation in southwest Madagascar over the last millennium. *The Holocene*, 32(1–2), 57–69.

Reddy, S.J. (1984). *General climate of Mozambique*. Comunicação no. 19a, Série Terra e Água. Maputo, Mozambique: Instituto Nacional de Investigação Agronómica.

Rehn, E., Rowe, C., Ulm, S., Woodward, C., Zawadzki, A., Jacobsen, G., & Bird, M.I. (2022). Integrating charcoal morphology and stable carbon isotope analysis to identify non-grass elongate charcoal in tropical savannas. *Vegetation History and Archaeobotany*, 31(1), 37–48.

Scheel-Ybert, R. (2016). Charcoal collections of the world. *IAWA Journal,* 37(3), 489–505.

Schlachter, K.J., & Horn, S.P. (2010). Sample preparation methods and replicability in macroscopic charcoal analysis. *Journal of Paleolimnology,* 44, 701–708.

Scott, A.C. (2010). Charcoal recognition, taphonomy and uses in palaeoenvironmental analysis. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 291(1–2), 11–39.

Shanahan, T.M., McKay, N.P., Hughen, K.A., Overpeck, J.T., Otto-Bliesner, B., Heil, C.W., King, J., Scholz, C.A., & Peck, J. (2015). The time-transgressive termination of the African Humid Period. *Nature Geoscience*, 8(2), 140–144.

Shetler, J.B. (2007). *Imagining Serengeti: a history of landscape memory in Tanzania from earliest times to the present*. Athens, OH, USA: Ohio University Press.

Sinclair, P., Ekblom, A., & Wood, M. (2012). Trade and society on the south-east African coast in the later first millennium AD: the case of Chibuene. *Antiquity*, 86(333), 723–737.

Snijders, F.L. (1985). *Land use inventory of Mozambique*. Série Terra e Água, Communicação 43. Maputo, Mozambique: Instituto de Investigação Agrária de Moçambique.

Spear, T. (2000). Early Swahili history reconsidered. *The International Journal of African Historical Studies*, 33(2), 257–290.

Steinberga, D., & Stivrins, N. (2021). Fire frequency during the Holocene in central Latvia, northeastern Europe. *Estonian Journal of Earth Sciences*, 70(3), 127–139.

Stoorvogel, J.J., & Smaling, E.M.A. (1990). *Assessment of soil nutrient depletion in sub-Saharan Africa: 1983–2000, vols. 1–4*. Report 28. Wageningen, the Netherlands: The Winand Staring Centre.

Syvitski, J.P.M. (1991). *Principles, methods, and application of particle size analysis*. Cambridge, UK: Cambridge University Press.

Thompson, L.G., Mosley-Thompson, E., Davis, M.E., Henderson, K.A., Brecher, H.H., Zagorodnov, V.S., Mashiotta, T.A., Lin, P.N., Mikhalenko, V.N., Hardy, D.R., & Beer, J. (2002). Kilimanjaro ice core records: evidence of Holocene climate change in tropical Africa. *Science*, 298(5593), 589–593.

Timberlake, J., Chidumayo, E., & Sawadogo, L. (2010). Distribution and characteristics of African dry forests and woodlands. In: Chidumayo, E., & Gumbo, D.J. (eds.) *The dry forests and woodlands of Africa: managing for products and services*. London: Earthscan, pp.11–41.

Timberlake, J.R., Bayliss, J., Dowsett-Lemaire, F., Congdon, C., Branch, B., Collins, S., Curran, M., Dowsett, R.J., Fishpool, L., Francisco, J., & Harris, T. (2012). *Mt Mabu, Mozambique: Biodiversity and Conservation*. Report produced under Darwin Initiative Award 15/036. Kew, UK: Royal Botanic Gardens.

Timberlake, J., Darbyshire, I., Cheek, M., Banze, A., Fijamo, V., Massunde, J., Chipanga, H., & Muassinar, D. (2016). *Plant conservation in communities on the Chimanimani footslopes, Mozambique*. Report prepared for Darwin Initiative Award 2380. Kew, London, UK: Royal Botanic Gardens. 69 pp.

Timberlake, J.R., Osborne, J., & Matimele, H. (2019). *Mt Lico and Pico Muli, northern Mozambique – botanical and ecological report*. May 2019. Kew, London, UK: Royal Botanic Gardens. 30 pp.

Tomlinson, R.W. (1973). *The Inyanga Area - an essay in regional biogeography*. Series in Science Occasional Paper No.1. Salisbury, University of Rhodesia. 67pp.

Tomlinson, R.W. (1974). Preliminary biogeographical studies on the Inyanga Mountains, Rhodesia. *South African Geographical Journal*, 56(1), 15–26.

Turner, M.G., Collins, S.L., Lugo, A.L., Magnuson, J.J., Rupp, T.S., & Swanson, F.J. (2003). Disturbance dynamics and ecological response: the contribution of long-term ecological research. *BioScience*, 53(1), 46–56.

Umbanhowar, C.E., & McGrath, M.J. (1998). Experimental production and analysis of microscopic charcoal from wood, leaves and grasses. *The Holocene*, 8(3), 341–346.

Uno, K.T., Polissar, P.J., Jackson, K.E., & deMenocal, P.B. (2016). Neogene biomarker record of vegetation change in eastern Africa. *Proceedings of the National Academy of Sciences*, 113(23), 6355–6363.

Vachula, R.S. (2021). A meta-analytical approach to understanding the charcoal source area problem. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 562, 110111.

Vachula, R.S., & Richter, N. (2018). Informing sedimentary charcoal-based fire reconstructions with a kinematic transport model. *The Holocene*, 28(1), 173–178.

Vachula, R.S., & Rehn, E. (2023). Modeled dispersal patterns for wood and grass charcoal are different: Implications for paleofire reconstruction. *The Holocene*, 33(2), 159–166.

Vachula, R.S., Russell, J.M., Huang, Y., & Richter, N. (2018). Assessing the spatial fidelity of sedimentary charcoal size fractions as fire history proxies with a high-resolution sediment record and historical data. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 508, 166–175.

Voortman, R.L., & Spiers, B. (1981). *An outline of the agricultural resources of Mozambique*. Field document no.38 [map dated February 1982]. AGOA/MOZ/75/011. FAO/UNDP Land and Water Use Planning project. Maputo, Mozambique: FAO/UNDP.

Vos, H.C., Fister, W., Eckardt, F.D., Palmer, A.R., & Kuhn, N.J. (2020). Physical crust formation on sandy soils and their potential to reduce dust emissions from croplands. *Land*, 9(12), 503.

Wagenbrenner, N.S., Germino, M.J., Lamb, B.K., Robichaud, P.R., & Foltz, R.B. (2013). Wind erosion from a sagebrush steppe burned by wildfire: Measurements of PM_{10} and total horizontal sediment flux. *Aeolian Research*, 10, 25–36.

Wagenbrenner, N.S., Chung, S.H., & Lamb, B.K. (2017). A large source of dust missing in Particulate Matter emission inventories? Wind erosion of post-fire landscapes. *Elementa: Science of the Anthropocene*, 5.

Whitlock, C., & Larsen, C. (2001). Charcoal as a fire proxy. In Smol et al. (eds.) *Tracking environmental change using lake sediments: terrestrial, algal, and siliceous indicators.* DPER Volume 3. Dordrecht, Springer. pp.75–97.

Williams, D.D. (1996). Environmental constraints in temporary fresh waters and their consequences for the insect fauna. *Journal of the North American Benthological Society*, 15(4), 634–650.

Westerlink, R.M. (1996). *Evaluation of monthly precipitation data of Mozambique*. Nota Tecnica no.69b, Série Terra e Agua. Maputo, Mozambique: Instituto Nacional de Investigação Agronómica.

Wilkinson, P., Mitchell, J.G., Cattermole, P.J., & Downie, C. (1986). Volcanic chronology of the Men–Kilimanjaro region, Northern Tanzania. *Journal of the Geological Society*, 143(4), 601–605.

Wooller, M.J. (2002). Fossil grass cuticles from lacustrine sediments: a review of methods applicable to the analysis of tropical African lake cores. *The Holocene*, 12(1), 97–105.

Zech, M. (2006). Evidence for late Pleistocene climate changes from buried soils on the southern slopes of Mt. Kilimanjaro, Tanzania. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 242, 303–312.

Zech, M., Leiber, K., Zech, W., Poetsch, T., Hemp, A. (2011). Late Quaternary soil genesis and vegetation history on the northern slopes of Mt. Kilimanjaro, East Africa. *Quaternary International*, 243, 327–336.

Zech, W., Schad, P., & Hintermaier-Erhard, G. (2022). *Soils of the world*. Berlin, Heidelberg: Springer Berlin Heidelberg.

Tables and Figure Captions

Species (n=11)	**Habitat**	**Stems (count)**	**Stem density (per ha)**	**BA (cm^2)**	**BA (m^2 ha^{-1})**
Brachystegia spiciformis	woodland	12	300	5143.7	12.87
Combretum zeyheri	woodland	2	50	106.9	0.27
Empogona coriacea	forest understorey	1	25	25.5	0.06
Erythroxylum emarginatum	forest understorey	25	625	791.2	1.98
Macaranga capensis	forest gap, margin	12	300	3153.9	7.88
Newtonia buchananii	forest	1	25	2083.3	5.21
Oxyanthus speciosus	forest understorey	1	25	88.3	0.22
Psychotria zombamontana	forest understorey	6	150	294.6	0.74
Pteleopsis myrtifolia	woodland	2	50	262.8	0.66
Pterocarpus angolensis	woodland	1	25	1046.5	2.62
Tricalysia pallens	forest understorey	5	125	159.5	0.40
Total	NA	68	1700	NA	32.90

Table 1: Results of tree community with bole diameter >5 cm dbh in forest plot C1 beside the soil pit. Species in plot = 11. Acronyms, NA, not applicable; BA, basal area.

List of Figure Captions

FIGURE 1 Photographs of (a) Mount Lico, Mozambique, located at geographic coordinates 15.792 °S, 37.363 °E, and (b) a view of the surrounding landscape from Mount Lico. Both (c) and (d) show examples of evergreen and semi-deciduous forest on top of Mount Lico. (e) Satellite-based view of Mount Lico and surrounding patches of agricultural and forested landscape showing the study site soil pit location (solid white square), 20x20 m forest plot (open white square) and the apparent east-west moisture gradient and approximate ecotone between forest types. Photographs (a–c), Phil Platts, and (d), Simon Willcock, May-June 2018. Satellite image dated May 2021 accessed through Google Earth Pro version 7.3.4.8642 (64-bit) with 2.0× vertical exaggeration to show topographic relief (Google LLC/Maxar Technologies, 2022).

FIGURE 2 Photographs of the (a) 2.2 m deep soil pit profile on Mount Lico, and (b–c) subsample collection down the soil profile. Photographs (a), Phil Platts, and (b–c), Simon Willcock, May 2018.

FIGURE 3 Summary results of the 220 cm soil profile. Note the limited O layer and relatively weak differentiation of the A and B horizon colouration at 50 cm. Radiocarbon age determinations and a linear interpolation age-depth model of the calibrated radiocarbon ages (black squares, n=3, see Supplemental Table 1; SHCal20; Hogg et al., 2020). Soil density and textural measurements and loss-on-ignition organic content estimated. Sieved soil charcoal results that show concentration and accumulation rate values.

FIGURE 4 Digital photographs of wet sieved subsamples. (a) Herbaceous charcoal, imperfect fragmented morphotype B5, at 20–22 cm depth (809–896 cal BP). (b) The three most abundant very coarse silt and sand grains throughout the core, quartz, magnetite, and reddish cemented clastic aggregates, at 50–52 cm depth (2133–2222 cal BP). (c) Sand grains and charcoal pieces photographed at low power magnification (5x) from 140–142 cm depth (5421–5487 cal BP). (d) Larger 3-dimensional blocky and long charcoal (morphotype E, 3-dimensionality is less apparent in photograph) fragment of non-woody plant part, highly resistant to entrainment, at 176–178 cm depth (6615–6681 cal BP). Black scale bar represents 200 μm.

FIGURE 5 Idealised charcoal morphotypes found in the Mount Lico soil pit profile (>125 μm). The apparent dimensionality of charcoal pieces visually observed at 10–40x magnification (apparently 2 or 3 dimensional) and qualitative entrainable index value designated for each morphotype are shown in grey text (Table S2 and Figures 6 and 7). Solid black top faces on 3-dimensional charcoal represent solid internal, white top faces represent an open internal 3-dimensional morphotype.

FIGURE 6 Charcoal morphology assemblage (>125 μm). A1 to D6 morphotype classifications and a single other type (morphotype E) (Figure 5). Cumulative total morphotype classes, Polygonal (Type A), Blocky (Type B) and Elongate (Type D) charcoal. Entrainable index 1 = easily entrainable and transported by air or water, and 5, resistant to transport entrainment and tends to remain locally deposited scaled by relative abundance (Table S2).

FIGURE 7 Select Mount Lico soil pit data (Figures 3, 5) and the accumulation rate of entrainable charcoal (sum of charcoal morphotype accumulation rates by each index value, 1–5; Figure 6). Paleoclimate reconstruction stacks of mean annual temperature anomaly reconstruction and precipitation of the wettest quarter of the year, binned to 100 year time steps (black lines) with 10% confidence envelope (grey lines) (Chase et al., 2017, paleoclimate product resolution of 100 year time steps). Generalised summary of past land use changes in eastern Africa based on published archaeological evidence and historical ecology studies (Morais, 1984; Nurse and Spear, 1985; Spear, 2000; Lane, 2004; Ekblom, 2012, 2018; Ekblom et al., 2011, 2014, 2016; Sinclair et al., 2014; Fleisher et al., 2015; Chami and Ntandu, 2018; Marchant et al., 2018; Ichumbaki and Pollard, 2021).