Human-woodland interactions during the Pre-Aksumite and Aksumite periods in northeastern Tigray, Ethiopia: insights from the wood charcoal analyses from Mezber and Ona Adi

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Received: 29 January 2020 / Accepted: 26 January 2021 / Published online: 2 March 2021
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Abstract
The Tigray region in Ethiopia witnessed the rise and fall of the Pre-Aksumite and Aksumite communities between the mid 2nd millennium BCE and the late 1st millennium CE. Despite the importance of these entities in recent African prehistory, the issue of how they interacted with their surrounding environment has only been addressed very recently. Here, we present the first systematic anthracological analysis from the region. Wood charcoal samples from two archaeological sites were analysed, the Pre-Aksumite rural site of Mezber (ca. 1600 BCE-1 CE) and Ona Adi (ca. 600 BCE-700 CE), an urban centre occupied continuously from the Late Pre-Aksumite period to the fall of the Aksumite kingdom. A total of 2,708 charcoal fragments from 25 samples and nine archaeological phases were analysed and 19 plant taxa associated with at least three different vegetation types were identified. The results demonstrate rather stable environmental conditions at a local level, with no major or abrupt environmental changes. They also evidence a process of landscape degradation as a result of human activity during the early to mid 1st millennium BCE, as well as a subsequent recovery that occurred gradually during the next ca. 1,500 years. Finally, differences in firewood use were identified in relation to the rural or urban nature of each settlement, showing an evolution in wood selection, management and strategies of use which indicates that both Pre-Aksumite and Aksumite peoples had a significant degree of resilience and adaptive capacity.

Keywords Archaeobotany · Charcoal analysis · Pre-Aksumite period · Kingdom of Aksum · Tigray · Ethiopia · Aksumite · Aksum

Introduction
Pre-Aksumite and Aksumite communities, which flourished in the Tigray region of Ethiopia between the mid 2nd millennium BCE and the late 1st millennium CE (Harrower and D’Andrea 2014; D’Andrea et al. 2018; Taddesse 2019) represent two of the most notable ancient cultural horizons of recent African prehistory. During this period, these transformed from farming communities into a complex literate civilization spanning the Ethiopian and Eritrean highlands (Fattovich 2012). Nonetheless, these ancient polities of the Horn of Africa are still incompletely known, as archaeological research there has been overshadowed by other contemporary civilizations such as ancient Egypt, Meröe in northeastern Sudan, and the Greco-Roman world. Recent research in Tigray has provided important insights to our understanding of relationships of humans with their environment during these millennia (Boardman 1999, 2000; D’Andrea et al. 1999, 2008a, b, 2011, 2018; Cain 2000; D’Andrea 2003,
2008; Lyons and D’Andrea 2003; Sernicola 2008; French et al. 2009, 2017; Terwilliger et al. 2011; Harrower and D’Andrea 2014; Sulas 2014; Graniglia et al. 2015; Woldekiros and D’Andrea 2017; Harrower et al. 2020). However, the issue of woodland use remains largely unexplored, as no charcoal analyses from human deposits have been published so far (but see Gebru et al. 2009). This paper presents the results of anthracology (charcoal study) from two archaeological sites in the Gulo Makeda district in eastern Tigray (Fig. 1), the Pre-Aksumite rural site of Mezber and the Aksumite urban centre of Ona Adi, both excavated as part of the Eastern Tigray Archaeological Project (ETAP) (D’Andrea et al. 2008a). As such, this work constitutes pioneer research in defining interactions between humans and woodland using archaeobotanical data to reconstruct how people used woodlands and by exploring the social and ecological behaviours that underlay the gathering and use of wood resources during the Pre-Aksumite and Aksumite periods.

Cultural background

The Pre-Aksumite period (> 800–50 BCE)

The term Pre-Aksumite refers to human occupations in the northern highlands of Ethiopia between the 1st millennium BCE and the rise of the Aksumite civilization ca. 50 BCE. During these centuries, the region experienced a substantial increase in settlement density, accompanied by the appearance of diverse agropastoral economies and social differentiation (Phillipson 2009). Based on pottery typology, this horizon is usually divided in three sub-phases, Early, Middle and Late Pre-Aksumite, with radiocarbon dates that vary significantly between subregions (Fattovich 2004; Michels 2005; Bard et al. 2014). Recently dates older than 800 cal BCE have been obtained at the site of Mezber (Harrower and D’Andrea 2014), hence introducing a fourth sub-phase named Initial Pre-Aksumite (1600–800 BCE).

Excluding the Initial phase at Mezber, two types of settlement have been found in the northern highlands during the Pre-Aksumite period: first, elite settlements such as Yeha (Fattovich 2009; Phillipson 2012, pp. 24–32), which contained elaborate monumental architecture and dedicatory inscriptions, both considered symbols of power; and second, non-elite villages built of undressed rough dry stonework (Phillipson 2012) that seem to represent the majority of settlements in Tigray (D’Andrea et al. 2008a; Sernicola 2008). Settlement pattern analysis shows associations between sites and their surrounding environment, including preferential selection of agriculturally more productive areas with available water (Sernicola and Sulas 2012; Harrower and D’Andrea 2014). Cultivated crops are well known as both African C₄ cereals and Near Eastern C₃ crops have been found throughout the region (Boardman 1999, 2000; D’Andrea et al. 2008b, 2011; Schmidt 2009; Beldados et al. 2015) along with zooarchaeological evidence of domesticated animals such as cattle, caprines, chicken, dog and donkey (Cain 2000; Shoshani et al. 2008; Lesur et al. 2014; Woldekiros and D’Andrea 2017).

The Aksumite Kingdom (50 BCE-700 CE)

The emergence and development of the Aksumite civilization was a gradual process. Its origins can be traced back to the last centuries BCE, specifically in the Aksum area, where a polity centred on Beta Giyorgis has been identified as Proto-Aksumite (ca. 400–50 BCE). This phase has been called Pre-Aksumite to Aksumite Transition (PA-A Transition) elsewhere in Tigray (Taddesse 2019, p. 339). From Beta Giyorgis, Aksumite regional and interregional influences rapidly consolidated during the Early/Classic Aksumite period (ca. 50 BCE-350 CE) (Bard et al. 2014; Taddesse 2019), allowing this new polity to extend its political and economic control over the previously distinct Pre-Aksumite populations (Phillipson 2012). Settlement patterns show a general continuity in occupation from previous Pre-Aksumite sites (for example, Anfray 2012; Taddesse 2019), as do subsistence economies (Bard et al. 2000; Boardman 2000; Cain 2000; D’Andrea et al. 2008b, 2011).

According to historical sources from outside the area (Kobishchanov 1979; Munro-Hay 1991; Phillipson 1998), there was an important territorial expansion in the 3rd century CE, with various kings of Aksum incorporating new territories into a centralized state, which adopted Christianity in the 4th century CE, marking the beginning of the...
Middle Aksumite phase (ca. 350–500 CE) (Bard et al. 2014; Taddesse 2019). This featured a stratified society with urban centres such as Matara (Anfray 2012) or Beta Samati (Harrower 2019) that was organized by complex political, administrative and military structures, minted its own official currency and maintained varying degrees of contact with foreign populations, both near and far (Phillipson 2012, pp. 71–106, 181–208; Fattovich 2019). Nonetheless most Aksumite sites were rural food-producing settlements; the number in mid-sized urban centres increased steadily until the 6th century CE. Available information points to differences in productive activities between urban and rural areas, the former featuring crafts which included metalworking and the making of glass and ivory artefacts (Phillipson 2012), although the division was rarely rigid and available archaeological data are still incomplete.

The Late Aksumite period (ca. 500–700 CE) marked the beginning of the Aksumite decline (Bard et al. 2014; Taddesse 2019). Archaeological evidence suggests a social and economic crisis at Aksum during this time, as reflected by the gradual reduction urban occupation and economic wealth (Fattovich 2010; Phillipson 2012). Nonetheless, a considerable number of rural compounds persisted (Sernicola and Sulas 2012) not only around Aksum, but also in other areas of the kingdom where the population is believed to have decreased only slightly (Sernicola 2008; Phillipson 2012; Harrower and D’Andrea 2014).

**Environment and vegetation**

The Tigray plateau extends over a total area of ca. 50,000 km² along the northern Ethiopian highlands and is drained by the Tezeke and Mareb rivers. The geology of the area is mainly shaped by the volcanic activity associated with the East African Rift system, which has resulted in a landscape dominated by an irregular plateau ranging from 1,000 to 3,500 m a.s.l. (Machado et al. 1998; Hagos et al. 2002). Tigray has a semi-arid, subtropical climate, characterized by strong seasonality (Machado et al. 1998), with a main rainy season from June to mid-September (Araya et al. 2010). The marked variations in topography and altitude greatly influence environmental conditions, producing different microclimates within short distances (Hagos et al. 2002) in which mean annual temperatures range from 15 to 25 °C, while mean annual rainfall ranges between 500 and 750 mm (Hadgu et al. 2013).

The region is highly sensitive to environmental changes due to its geographical position and mountainous terrain (Machado et al. 1998). As shown by palaeoclimatic records from fluviolacustrine (river and lake) sediments (Trauth et al. 2007; Lanckriet et al. 2015), marked environmental variation has characterized the Tigray Plateau since at least the Early Pleistocene (ca. 2.5 mya), with a general tendency towards aridification, alternating with relatively wet periods until the beginning of the Holocene, when the East African Humid Period began (ca. 9000–3600 BCE) (Nyssen et al. 2004; Tierney et al. 2011). Nonetheless, dry events are known during these moister millennia (Marshall et al. 2009, 2011), which finally changed to a period of landscape destabilization and reduced precipitation, reaching its driest level from 2200 BCE onwards (Lanckriet et al. 2017), when present-day climatic conditions were established (Bard et al. 2000). The subsequent centuries featured a significant increase in sediment supply (Machado et al. 1998) and colluvial activity (Moeyersons et al. 2006), while C₄ plants became increasingly abundant (Gebru et al. 2009). Such a tendency would have reached its peak between 800 and 500 BCE, when there was a rapid decline of Afromontane forests, substituted by Afromontane woodlands and grasslands that persisted until the beginning of the 2nd millennium CE (Bard et al. 2000; Darbyshire et al. 2003; Sulas et al. 2009). The shift to a relatively wetter climate between 450 BCE and 500 CE, along with a decreased soil erosion rate (Ciampalini et al. 2008) and lesser sediment supply (Machado et al. 1998) allowed landscape stabilization (French et al. 2009). At this period, pollen analyses indicate a predominance of grasses together with some trees and shrubs related to wooded grassland environments, as well as Afromontane forests (Bard et al. 2000; Darbyshire et al. 2003; Sulas et al. 2009). After 500 CE, the landscape in the highlands started to degrade once again. Geoarchaeological research has shown that loss of woodland and intensification of land use related to the Aksumite kingdom led to erosion and soil degradation (French et al. 2017). This tendency would have lasted for at least 300 years, until the beginning of the 9th century CE, when geoarchaeologists have identified the last major period of landscape recovery (Machado et al. 1998; Bard et al. 2000).

Presently the area is largely devoid of wooded vegetation, with almost all available land under cultivation or pasture. Nonetheless, based on colonial sources most scholars agree that a large area of the northern highlands of Ethiopia was forested in earlier times (references in Bard et al. 2000). Due to the lack of research, ecological and bioclimatic data have been used to reconstruct the distribution of past vegetation communities. According to Bard et al. (2000, pp. 67–69) the Tigray region featured great floristic complexity, especially in relation to altitude. The primary vegetation was dry evergreen montane forest dominated by *Juniperus procera* and *Olea europaea* ssp. *cuspidata* at altitudes above 2,200 m, mixed *Podocarpus-Juniperus* forest in wetter areas between 1,400 and 2,200 m and *Acacia* wooded grassland below 2,200 m. Available analysis of natural soil charcoal confirms the presence of both *Juniperus-Olea* forests and *Acacia* wooded grasslands on the Tigray Plateau from
7,800 years ago until today (Gebru et al. 2009; Terwilliger et al. 2011). How such a natural woodland landscape evolved into the current vegetation patterns has yet to be resolved. Most explanations suggest the double effect of climate change and human activities (Butzer 1981; Bonnefille and Mohammed 1994; Machado et al. 1998; Bard et al. 2000; Darbyshire et al. 2003; Gebru et al. 2009), though the details about their relative significance remain unknown. Modern botanical surveys (Friis 1992; Friis et al. 2010; Kindt et al. 2011a, b, c; van Breugel et al. 2015) over the past 30 years have added further complexity to the current vegetational landscape of Tigray (Table 1). According to van Breugel et al. (2015), the northeastern regions of modern Tigray are covered by a combination of predominant undifferentiated (DAF/U) and dry single dominant (DAF/SD) Afromontane forests, along with significant areas of Afromontane woodlands, wooded grasslands and grasslands (DAF/WG). Friis et al. (2010) notes that Afromontane forests (DAF) can be understood as a gradient from wetter (DAF/U) to drier (DAF/SD and DAF/WG) types. More importantly, DAF/WG represents a degradation type of DAF, sharing an increasing number of taxa with more arid vegetation units from lower altitudes such as Acacia-Commiphora woodlands and bushlands proper (ACB), Acacia wooded grasslands of the Rift Valley (ACB/RV) or desert and semi-desert scrubland (DSS) (Friis et al. 2010). ACB and ACB/RV are recorded in the lower margins of the Tigrinya highlands, especially in the eastern escarpment leading to the lowlands of the Afar region, mostly characterized by DSS scrubland (Friis et al. 2010; van Breugel et al. 2015). The rest of the province is dominated by Combretum-Terminalia woodlands and wooded grasslands (CTW) (van Breugel et al. 2015). Finally, small patches of vegetation associated with the Ericaceous (EB) and Afroalpine (AA) belts can be found throughout the entire Tigrinya highlands at altitudes above 3,000 m (Friis et al. 2010; van Breugel et al. 2015).

**Study area**

Located 15 km north of Adigrat, the Gulo Makeda region was recognized as a part of the Pre-Aksumite and Aksumite territories long ago (Anfray 1973; Michels 1988; Munro-Hay 1991). Available archaeological evidence indicates that people have occupied Gulo Makeda for at least 3,000 years (Harrouwer and D’Andrea 2014) and several archaeological sites have been described from there (Rossini 1928; Coulbeaux 1929; Mordini 1941; Cuquot and Drewes 1955; Anfray 1966, 1972, 1973, 1974; D’Andrea et al. 2008a; Sernicola 2012; Harrouwer and D’Andrea 2014). Although numerous, these sites are generally smaller than those in western Tigray (Harrouwer and D’Andrea 2014).

The Eastern Tigray Archaeological Project (ETAP) is currently carrying out interdisciplinary studies with the aim to better understand how Pre-Aksumite and Aksumite populations interacted with their surrounding environments. The present paper explores the cultural and socio-ecological behaviours that underlie the gathering, management and use of wood resources as fuel, by analysing charcoal samples from the archaeological sites Mezber and Ona Adi. Both were inhabited during times of critical cultural developments, and together they provide a unique occasion to question the differences between rural and urban settlements, and domestic and elite status, in terms of wood availability and use, but also to investigate interactions of people with their environment, and their evolution between the mid 2nd millennium BCE and the late 1st millennium CE.

**Mezber**

The site of Mezber (Aby Adi, Tabia Addis Alem) covers approximately 0.83 ha and lies on a slightly raised hillside situated in a valley bottom adjacent to an intermittent stream at 2,242 m (Woldekiros and D’Andrea 2017). Archaeological work has found an extended occupational sequence dated from 1600 cal BCE to 1 cal CE. No other site in the region has recorded such an early occupation with associated Pre-Aksumite cultural materials. Based on pottery, stratigraphy and radiocarbon dating, four Pre-Aksumite horizons with at least two building construction phases have been described. The earliest occupation of the site dates to the Initial phase (ca. 1600–900 BCE) and is followed by Early (ca. 850–750 BCE), Middle (ca. 600–400 BCE) and Late (ca. 400 BCE–1 CE) Pre-Aksumite phases. The site is one of only a few known Pre-Aksumite sites that have not been disturbed by later settlement. Archaeobotanical, zooarchaeological and isotopic evidence from Mezber indicates a fully developed agropastoral economy (Woldekiros and D’Andrea 2017; Beldados pers. comm.). The site has produced large-scale domestic architecture, suggesting the presence of wealthy or elite people in the Early phase, as well as evidence of specialized hide-working craft production in the Middle phase (Peterson 2017). The site was abandoned at the beginning of the 1st century CE for unknown reasons.

**Ona Adi**

Ona Adi is located near the modern villages of Menabéity and Etchmear (Tabia Shewit Lemlem) at 2,452 m. The site is estimated to cover around 10 ha (Harrouwer and D’Andrea 2014) and was occupied ca. 750 BCE–700 CE (Taddesse 2019). The pottery sequence demonstrates that the site was occupied during the PA-A Transition, with five occupational phases, Mid/Late Pre-Aksumite (ca. 750–400 BCE), PA-A Transition (ca. 400–1 BCE), Early Aksumite (ca. 1–330 CE),
Middle Aksumite (ca. 330–500 CE) and Late Aksumite (ca. 500–700 CE) (Taddesse 2019, p. 339). It is noteworthy as the only systematically investigated site that has a record of occupation during the PA-A transition, a period of cultural transformation which involved changes in leadership and settlement abandonment in the regional centres of Yeha and Aksum (D’Andrea et al. 2008a). Further analyses of stone artefacts, animal bone, phytoliths and radiocarbon dating samples are currently ongoing.

### Materials and methods

#### Sampling

Bulk soil samples were recovered between 2007 and 2015 at both sites, following a systematic sampling strategy. They were then floated off site using a recirculating bucket flotation system. Sieves of both 1 and 0.25 mm meshes were used in order to separate coarse and fine fractions, which were subsequently air dried. Charcoal remains were sorted from the light fraction samples using a Leica EZ4 stereo microscope at 7–30×. Charcoal samples for analysis were selected according to stratigraphical criteria in order to represent the complete chronological and cultural sequence of both sites. They were all recovered from non-specialized long-term deposits to obtain a reliable environmental signature. A total of 25 samples from nine different archaeological phases were weighed and separated for analysis (Table 2).

### Identification, reference collection and data analysis

Identification of charcoal fragments was carried out at the archaeobotanical laboratories of the Muséum National d’Histoire Naturelle, Paris (MNHN), and Pompeu Fàbrab University, Barcelona (UPF), using a reflected light microscope with magnifications between 50 and 1,000×. The charcoal specimens were described following the codes proposed in the International Association of Wood Anatomists (IAWA) list of microscopic features for the identification of both hardwood (Wheeler et al. 1989) and softwood (Richter et al. 2004). Taphonomic features such as charcoal fragment size (<5 mm/5–10 mm/<10 mm) and the presence of natural alterations (wood compression, tree ring alteration), biological changes (collapsed cells, insect and other damage, fungal attack), combustion (radial cracks, vitrification), and post-depositional alterations (mineralisation or cell structure deformation) (Fig. 2) were recorded as proposed by Allué et al. (2009).
Taxonomic identification was achieved following the methodology proposed by Höhn and Neumann (2018) for charcoal identification in species rich environments and by comparing the charcoal with modern reference material produced specifically for this study with samples obtained from the wood collections of the MNHN in Paris, and the charcoal reference collection of the AASPE unit (UMR 7209, CNRS-MNHN). Plant taxa for this reference material were selected according to their importance amongst the vegetation units described by Friis et al. (2010) and their availability in the collections. The uncharred wood samples were prepared for microscopic observation at the MNHN, following an adaptation of the procedure described by Orvis et al. (2005). Anatomical descriptions and images of all reference materials are available at the Universitat Pompeu Fabra e-Repository (https://repository.upf.edu/handle/10230/43106). Online databases (InsideWood 2004 onwards) and published atlases were used to help and refine the identifications (for example, Fasolo et al. 1939; Metcalfe and Chalk 1950a, b; Neumann et al. 2001; but see references in ESM 1).

The data were analysed using relative frequencies of the number of remains by charcoal taxon, but also according to the vegetational units proposed by Friis et al. (2010), associating each of the taxa with the ecological groups in which they are common or predominant Table 3, following previous research (Friis et al. 2010; Kindt et al. 2011a, b, c; van Breugel et al. 2015). The main vegetational units (ecological groups) present in modern northeastern Tigray are included (van Breugel et al. 2015). Their frequencies were calculated by adding up the frequencies of the taxa associated with them. Unidentifiable fragments were excluded from the data analysis. Various indices and ratios were used in order to assess taphonomic processes. These are the fragmentation/preservation index (Lancelotti 2010), density index (Asouti 2003), assemblage biodiversity and taxa distribution, Simpson’s diversity index (Branch et al. 2005), Pielou’s evenness index (Pielou 1966) and the ubiquity rate (Miller 1988; Popper 1988) (ESM 2). In order to evaluate representativity of the assemblages in the original deposits, we used effort curves, both qualitative and quantitative (Chabal et al. 1999; Asouti and Austin 2005). The Gini-Lorenz index (Scheel-Ybert 2005; Dotte-Sarout et al. 2015) was applied to measure the ecological representativity of the assemblage. Statistical analyses were done using PAST (Hammer et al.

| Site | Phase       | Field: Locus | Locus | Archaeological context | Sample number | Flotation volume (l) | Charcoal remains (g) | Analysed fragments |
|------|-------------|--------------|-------|------------------------|---------------|---------------------|---------------------|--------------------|
| MBR  | Initial Pre-Aksumite | A1:54        | 108   | Living surface         | 1126          | 0.2                 | 0.28                | 232                |
|      |             | A1:54        | 109   | Living surface         | 1337          | 5                   | 1.55                | 232                |
|      |             | A1:55        | 110   | Living surface         | 1345          | 3.25                | 0.61                |                    |
| Early Pre-Aksumite | A1:61       | 114   | Midden                | 1585          | 9                   | 7.88                |                    |
|      |             | A1:67        | 146   | Infill                 | 1908          | 10                  | 6.86                | 315                |
|      |             | A1:74        | 156   | Infill                 | 2106          | 10                  | 5.40                |                    |
| Middle Pre-Aksumite | A1:72       | 154   | Infill                 | 2096          | 8                   | 2.87                |                    |
|      |             | A1:73        | 155   | Living surface         | 2102          | 7.25                | 3.59                | 310                |
|      |             | A1:73        | 155   | Living surface         | 2110          | 4                   | 7.55                |                    |
| Late Pre-Aksumite | A1:10       | 42    | Infill                 | 18            | 0.3                 | 0.58                | 306                |
|      |             | A1:10        | 45    | Infill                 | 20            | 0.55                | 8.06                |                    |
| OA   | Late Pre-Aksumite | D1:13       | 23    | Infill                 | 1127          | 5                   | 0.55                |                    |
|      |             | D1:13        | 26    | Infill                 | 1139          | 7                   | 0.89                | 305                |
|      |             | D1:16        | 30    | Infill                 | 1163          | 4.5                 | 7.35                |                    |
| PA-A Transition | D1:13       | 22    | Living surface         | 769           | 6                   | 4.26                |                    |
|      |             | D1:14        | 24    | Infill                 | 1131          | 4                   | 8.05                | 310                |
|      |             | D1:15        | 29    | Infill                 | 1157          | 2.5                 | 3.04                |                    |
| Early Aksumite | D1:10       | 18    | Infill                 | 1106          | 4                   | 5.19                |                    |
|      |             | D1:10        | 19    | Infill                 | 1110          | 6                   | 24.95               | 319                |
|      |             | D1:10        | 20    | Infill                 | 1118          | 5                   | 3.26                |                    |
| Middle Aksumite | D1:7         | 13    | Infill                 | 811           | 7                   | 2.56                |                    |
|      |             | D1:9         | 14    | Infill                 | 818           | 4                   | 5.50                | 305                |
|      |             | D1:10        | 17    | Infill                 | 843           | 4                   | 5.85                |                    |
| Late Aksumite | D1:3         | 5     | Living surface         | 711           | 7                   | 8.18                | 306                |
|      |             | D1:6         | 7     | Infill                 | 722           | 8                   | 9.70                |                    |
Fig. 2 Microscopic photos showing examples of different alterations observed in Mezber and Ona Adi charcoal assemblages. (a), wood compression; (b), cell collapse due to xylophage activity; (c), fungal hyphae infestation; (d) radial cracks and vitrification; (e), charcoal mineralisation; (f), cell structure deformation
Results

Taphonomy

Taphonomical alterations are presented in Fig. 3. No phase has more than 60% of taphonomically affected charcoal fragments; overall means are 38% for Mezber and 48% for Ona Adi. The alteration ratios are rather similar throughout the sequences of both sites. The most common alterations are associated with combustion (X = 27%) and post-depositional processes (X = 18%), but natural and biological agents show very low impacts in all phases (<4%). Despite such a degree of alteration, the fragmentation/preservation index (F/P) remains low (X = 10%), meaning that the general state of preservation allowed proposed identifications for 90% of the charcoal fragments. Density, Simpson’s diversity and Pielou’s evenness indices were calculated and compared against the taphonomically data by phase and type of context. The results show no correlation, indicating that taphonomy did not severely impact charcoal density or taxon diversity, hence suggesting that the studied assemblage was well preserved. The raw data are available in ESM 3.

Taxonomic results

A total of 2,708 charcoal fragments were studied, of which 2,428 were identified at various taxonomic levels. The raw data are available in ESM 5. Twenty-three different plant taxa were identified, both angiosperms (21) and gymnosperms (2). Identifications were proposed for all types except three angiosperms, which remain unidentified. We found four distinct Acacia types, although their identification to species level was not possible and they are therefore grouped and listed as Acacia spp. Detailed anatomical descriptions and images of the 17 identified charcoal types, as well as a discussion of each identification can be found in ESM 1. Tables 3 and 4 summarise both the ecological distributions and wood features of the identified taxa.

Table 3 Summary of the ecological distributions of the identified taxa

| Identified taxa       | Altitude (m a.s.l.) | DAF/U | DAF/SD | DAF/WG |
|-----------------------|---------------------|-------|--------|--------|
| Acacia spp.           | 0-3,100             |       | ***    |        |
| Carissa spp.          | 550-2,500           |       |        | ***    |
| cf. Boscia spp.       | 50-1,900            | **    | **     |        |
| Crotot spp.           | 500-2,350           | **    | **     | ***    |
| Dodonaea angustifolia | 500-2,900           |       |        | ***    |
| Hagenia abyssinica    | 2,450-3,250         | **    | **     |        |
| Juniperus procera     | 1,100-3,500         | ***   | ***    |        |
| Maerua spp.           | 0-2,100             |       | **     |        |
| Maytenus spp.         | 380-3,500           | **    | **     | ***    |
| Nuxia spp.            | 800-3,800           |       |       |        |
| Olea spp.             | 1,250-3,200         |       | **     | ***    |
| Pittosporum spp.      | 1,400-3,200         | **    | **     |        |
| Podocarpus falcatus   | 1,350-2,900         | ***   |        | **     |
| Rhamnus spp.          | 1,175-3,200         | **    | **     | ***    |
| Rhus spp.             | 700-2,800           |       |        | ***    |
| Rubiaceae cf. Ixoroideae | 400-3,000     | **    | **     | ***    |
| Ziziphus spp.         | 0-2,400             |       | **     |        |

After Friis et al. (2010), Kindt et al. (2011a, b, c) and van Breugel et al. (2015): *, present, but of minor importance; **, common; ***, predominant; grey shading, included in analysis as part of the vegetational unit

The quantitative and taxonomic curves from all phases are recognized as saturation curves, showing a clear stabilization tendency after 200 fragments analysed, hence indicating that the taxon frequencies by phase are a fair representation of the originally deposited assemblage and that every significant taxon is represented (ESM 4). Finally, Gini-Lorenz index results vary between 30:70 and 23:77, with a rounded median of 26:74 for Mezber and 29:71 for Ona Adi (ESM 4). As such, both assemblages can be considered as representative of the past vegetation and no taxon appears to be significantly overrepresented.

Descriptive and quantitative results from Mezber

A total of 19 taxa, three unidentified, were recorded among the 1,163 charcoal fragments analysed from the Mezber samples. Angiosperms account for 98% of the total assemblage, which is dominated by Rhus spp. (27%), representing Afromontane woodlands, wooded grasslands and grasslands (DAF/WG), and Olea spp. (24%), representing the undifferentiated (DAF/U) and dry single dominant (DAF/SD) Afromontane forests. Despite the plant diversity and the predominance of Rhus and Olea, the assemblage shows a rather high species evenness, in which 79% of the taxa are represented by between 1 and 7% of the identified charcoal fragments. Indeed, the results by phase reveal a rather stable degree of biodiversity, with 13 taxa present in all phases. Still, variation through time is evident in plant distribution (Fig. 4).

The Initial Pre-Aksumite phase features less dominance of Rhus and Olea than the site average Acacia, which represents DAF/WG and Carissa for DAF/SD, accompany them. Unlike the following periods at Mezber, during this phase the use of wood appears to have been undifferentiated, with all vegetational groups used similarly and a more even distribution of taxa Fig. 4. The subsequent Early Pre-Aksumite phase indicates a higher rate of DAF/U and DAF/SD wood
use, whereas the percentage from DAF/WG is reduced. This assemblage is generally dominated by *Olea*, accompanied by *Rhus, Dodonaea angustifolia* and *Croton* spp. The DAF/U and DAF/SD gymnosperm *Juniperus procera* and DAF/U one *Podocarpus falcatus* both score under 3%, despite their potential dominance in their vegetational units, but both taxa reach their highest values of the site sequence in this phase. This situation changes during the Middle Pre-Aksumite phase, when *Olea* occurrence values are lowest compared to *Rhus*. During this phase, DAF/U and DAF/WG taxa are significantly reduced, whereas DAF/WG ones significantly rise, as clearly shown by lower-storey woodland taxa such as cf. *Boscia* sp. and *Dodonaea angustifolia*, even though the DAF/WG main taxon, *Acacia* spp., scores under 1%. Lastly, the Late Pre-Aksumite phase at Mezber shows a relative increase in *Olea* use compared with *Rhus*, while the rest of the taxa remain relatively stable. As a result, DAF/U and DAF/SD show a meaningful increase, although DAF/WG maintains its predominance.

**Descriptive and quantitative results from Ona Adi**

From Ona Adi, 1,545 charcoal fragments were studied and a total of 20 taxa were identified, including three unidentiﬁed angiosperms. Angiosperms account for 98% of the total assemblage, which is dominated by *Olea* spp. (25%) representing DAF/U and DAF/SD, along with *Acacia* (10%, DAF/WG) and *Carissa* (9%, DAF/SD). The Ona Adi assemblage features high diversity in all phases and 80% of the taxa are present in all phases. Figure 5 presents distribution of the taxa and their variation through the occupational phases.

Late Pre-Aksumite samples are dominated by *Carissa*, followed by *Olea* and *Rhus* spp. This phase features the lowest occurrence of the main DAF/WG genus *Acacia* while in the PA-A Transition phase, the assemblage mainly features *Olea* and *Acacia*. The main secondary taxa are from the DAF/WG vegetation, *Rhus* and cf. *Boscia* spp., as well as *Dodonaea angustifolia, Nuxia* spp. (both also present in DAF/SD), and *Maytenus* spp. (also in DAF/U), each showing values between 5% and 8%. The DAF/U and DAF/SD gymnosperm *Juniperus procera* scores 3%. In this phase, there is a rather even distribution of taxa between the three vegetational units that continues during the following Early Aksumite phase, with slight differences in the most common taxa. While *Olea* and *Carissa* increase slightly during this Early Aksumite phase, the presence of *Acacia*, as well as other secondary taxa from DAF/WG such as cf. *Boscia* and *Ziziphus*, is similarly reduced. This continuity extends to the Middle Aksumite occupation even though there are differences such as *Olea* dominance decreasing in favour of *Acacia*. At the same time, however, other DAF/U and DAF/SD taxa such as *Hagenia abyssinica* and *Podocarpus falcatus*, as well as the DAF/U and DAF/WG taxa *Maytenus* and *Croton* sp., respectively have their highest occurrences. Some of the secondary taxa exclusively associated with the DAF/WG vegetation such as cf. *Boscia* and *Maerua* spp. have their lowest values. Finally, even though the Late Aksumite phase shows a relative recovery of *Olea*, the overall distribution of the vegetational units stays similar, and the small decrease of *Acacia* is balanced by the relatively higher values of the secondary taxa from DAF/WG, such as cf. *Boscia* and *Maerua*, while the secondary taxa of DAF/U and DAF/SD such as *Hagenia abyssinica* and *Podocarpus falcatus* appear slightly reduced.

**Discussion**

**Landscapes and woodland vegetation**

Despite the well-known problems with palaeoenvironmental interpretations derived from anthropogenic assemblages (Chabal et al. 1999; Asouti and Austin 2005; Dotte-Sarout et al. 2015), the generally even distribution of plant taxa through the archaeological sequences of both Mezber and Ona Adi suggests that no major climate changes took place...
in northeastern Tigray during the Pre-Aksumite and Aksu-
mite periods, in accordance with natural soil charcoal and
geochemical isotope analyses in the region (Gebru et al.
2009; Terwilliger et al. 2011). The charcoal data from Mez-
ber and Ona Adi show that people were using wood from at
least three separate vegetation units, both undifferentiated
(DAF/U) and dry single dominant (DAF/SD) Afromont-
tane forests, as well as Afromontane woodlands, wooded
grasslands and grasslands (DAF/WG), throughout the entire
sequence of occupation at both sites. This is consistent with
the current vegetation of the landscape as described by van
Breugel et al. (2015), and it is also in accordance with pre-
sent vegetation distribution by altitude. Friis et al. (2010)
record the presence of DAF/U, DAF/SD and DAF/WG
between 1,400 and 3,200 m, and both Mezber (2,242 m)
and Ona Adi (2,452 m) are within this height range.

Previous palynological studies in more southern areas
of the northern Ethiopian highlands have suggested a sig-
nificant decline of Afromontane forests (DAF/U and DAF/
SD) between 800 and 500 BCE in Tigray province, and their
almost complete substitution by Afromontane wooded grass-
lands (DAF/WG) by the 2nd millennium CE (Bard et al.
2000; Darbyshire et al. 2003). According to these studies,
this deforestation process was the combined result of drier
environmental conditions and human activity. However, the
present study indicates that even if the use of wood from
taxa associated with the DAF/U and DAF/SD units declined
after the Early Pre-Aksumite phase (ca. 750 BCE), they con-
tinued to be consistently used after 400 BCE at both Mezber
and Ona Adi. On the one hand, this supports the argument
of human deforestation, as DAF/WG represents a degraded
type of Afromontane vegetation, mainly through human
impact (Friis et al. 2010). On the other hand, it indicates
that the decline of Afromontane forests (DAF/U and DAF/
SD) was not as widespread in space and time as previously
suggested by the pollen record (Bard et al. 2000; Darby-
shire et al. 2003). This discrepancy could be attributed to
varied environmental conditions within the region, as has
been described for modern Tigray (Hagos et al. 2002), where
a wide array of microclimates within very short distances
are recorded. In this sense, changes at regional scale might
have affected the studied area differently to some other areas,
so explaining the contradictions with the palaeoecological
studies from these southern regions (for example, Bard et al.
2000; Darbyshire et al. 2003; Sulas et al. 2009).

The rapid return to the use of Afromontane forest taxa
after the Late Pre-Aksumite phase overlaps with a change
to a relatively wetter climate and landscape stabilization
indicated at ca. 450 BCE by several authors (Machado et al.
1998; Ciampalini et al. 2008; French et al. 2009). The use
as fuel of taxa associated with the DAG/WG vegetation
such as Acacia increases by 10% from the PA-A Transition
(400 BCE-1 CE) onwards at Ona Adi. This could be associ-
ated with the previously mentioned expansion of DAF/WG.
Recent studies have shown no evidence of general changes
in climate and suggested that land clearing practices played
a more meaningful role in shaping the surrounding land-
scape (Terwilliger et al. 2011). The results presented in this
study support the hypothesis that such an increase in signs
of woodland clearance is the product of human activity and

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### Table 4
Summary of the features and uses of the identified wood taxa

| Identified taxa                  | Hardness | Quality as fuel | Resistance to pests | Durability | Other uses than fuel |
|----------------------------------|----------|----------------|---------------------|------------|----------------------|
| Acacia spp.                      | Hard     | Good           | Variable            | Durable    | Artefacts            |
| Carissa spp.                     | Hard     | Good           | Medium              | Durable    | Artefacts            |
| cf. Boscia spp.                  | Hard     | Good           | High                | Durable    | Artefacts            |
| Croton spp.                      | Soft     | Good           | Low                 | Perishable | Construction, artefacts |
| Dodonaea angustifolia            | Hard     | Good           | High                | Durable    | Artefacts            |
| Hagenia abyssinica               | Soft     | Good           | Low                 | Perishable | Construction, artefacts |
| Juniperus procera                | Medium   | Good           | High                | Durable    | Construction         |
| Maerua spp.                      | Hard     | Good           | Variable            | Durable    | Artefacts            |
| Maytenus spp.                    | Hard     | Good           | Variable            | Durable    | Construction         |
| Nuxia spp.                       | Hard     | Good           | Variable            | Durable    | Construction         |
| Olea spp.                        | Hard     | Good           | High                | Durable    | Construction, artefacts |
| Pittosporum spp.                 | Soft     | Bad            | Low                 | Perishable | Artefacts            |
| Podocarpus falcatus              | Soft     | Good           | Low                 | Perishable | Construction         |
| Rhamnus spp.                     | Hard     | Good           | Variable            | Durable    | Artefacts            |
| Rhus spp.                        | Soft     | Good           | Low                 | Perishable | Construction, artefacts |
| Rubiaceae cf. Ixoroideae         | Variable | Variable       | Variable            | Variable   | Various              |
| Ziziphus spp.                    | Hard     | Good           | High                | Durable    | Construction         |

von Maydell (1990), Ruffo et al. (2002), Bekele-Tesemma (2007), Louppe et al. (2008), Gebreselassie et al. (2014)
may not be related to environmental changes. A comparable situation can be observed at ca. 500–800 CE, when a period of environmental degradation has been found (Marshall et al. 2009; French et al. 2017). During this time, Middle and Late Aksumite phases at Ona Adi show continuity in woodland use, as no significant changes are identified. This indicates that the abandonment of Ona Adi after ca. 700 CE, coinciding in time with the disappearance of the Aksumite Kingdom, was not related to an extreme deforestation process resulting from intense human land-clearing activities.

**Firewood selection and management strategies at Mezber and Ona Adi**

The charcoal data from both Mezber and Ona Adi show that a great variety of types of wood were used. Twenty three taxa have been identified in the charcoal record, associated with at least three vegetational types. The taxa mostly have hard and durable wood which burns well as fuel. Notable exceptions, characterized by soft and easily perishable wood, include *Rhus, Hagenia abyssinica* and *Croton* spp. (von Maydell 1990; Ruffo et al. 2002; Bekele-Tesemma 2007; Louppe et al. 2008). Preferences and selection criteria are evident in both assemblages, so that favoured types of wood including *Rhus* and *Olea* at Mezber represent more than half of the assemblage, whereas at Ona Adi the most common taxa are *Olea, Acacia* and *Carissa*, with almost half of the total analysed charcoal fragments. The presence of lower quality firewood can be related to the accidental or deliberate burning of building timber and artefacts at the end of their uses. For example, *Pittosporum* spp. is known to be used for making basketry. The use of taxa whose wood smells bad when burnt, such as *Dodonaea angustifolia* or *Hagenia abyssinica* (Liu and Noshiro 2003; Gebreselassie et al. 2014), could be associated with a similar phenomenon, since the wood of both species is known to be suitable for building and making artefacts (Ruffo et al. 2002). Finally, Afrotropical forest gymnosperms such as *Juniperus procera* or *Podocarpus falcatus* were rarely used, although their presence in the studied region is well known from soil charcoal analyses, constituting up to 50% of the past woodland during Pre-Aksumite and Aksumite times (Gebru et al. 2009, p. 76). While *Podocarpus* wood does not burn well as fuel and is not durable, *Juniperus* firewood is high quality (Chudnoff 2007). They are both useful because they produce large quantities of dead biomass and are thornless. The virtual absence of *J. procera* in the charcoal record could be explained by both functionalist or symbolic reasons. Even though a cultural taboo is possible, as has been documented amongst the Konzo of southwestern Ethiopia (Amborn 2002), we argue that its low occurrence was probably due to the fact that these trees grow in closed forest. By examining the charcoal records from Mezber and Ona Adi it would seem that both Pre-Aksumite and Aksumite people did not enter closed forests for wood, but they gathered firewood from open forests and forest margins instead, as they were more accessible.

Despite the high degree of homogeneity in both assemblages, we argue that selection strategies may have changed through time, based on the distinctive characteristics of the wood used. First, during the Initial Pre-Aksumite phase at Mezber, a generalist approach to wood gathering is observed.
in which main and secondary taxa from all vegetation types were used in similar proportions. According to Asouti and Austin (2005), this type of strategy is characteristic of mobile hunter-gatherers and nomadic pastoralists. The presence of nomadic and semi-nomadic cattle herders in eastern Tigray since at least the 2nd millennium BCE is indicated by rock art (Fattovich 2019, pp. 254–255). The Initial Pre-Aksumite phase at Mezber thus represents one of the oldest Pre-Aksumite occupations of the Ethiopian highlands (ca. 1600–900 BCE), the origin of which has been linked to previous seasonal movements of pastoral communities from the lowlands of Sudan, as suggested by their pottery and stone artefacts, both associated with an agro-pastoral economy (Fattovich 2012; Phillipson 2017).

The Early Pre-Aksumite phase shows signs of wood selection and specialization. From this phase onwards, Afrotropical forest taxa (DAF/U and DAF/SD), and especially Olea, were preferred over other kinds of wood at Mezber. Availability, size and state of the wood were surely crucial factors, but its high quality as fuel, along with its hardness, durability and resistance to pests cannot have been overlooked (Bekele-Tesemma 2007; Gebreselassie et al. 2014). As very few Pre-Aksumite settlements have shown an occupation as ancient as at Mezber, the importance of the presence of specific desirable resources such as high quality firewood could have played a vital role in the prolonged occupation of the site. However, the overuse of Olea along with the period of forest degradation between 800 and 500 BCE (Darbyshire et al. 2003) would have rendered Olea wood less easily accessible, hence causing a change in the main source of firewood. Thus in the Middle and Late Pre-Aksumite phases at Mezber, Rhus was the main wood used instead of Olea. During these phases, Rhus was as abundant as Olea was during the previous phases, indicating that there was not a change in the firewood selection strategy, but merely the use of a newly preferred wood based on its availability and burning quality. The choice of Rhus as the Olea substitute can be understood, if we consider that both taxa share a similar ecological niche in their respective vegetational units, occurring on well-drained soils with good access to sunlight (Ruffo et al. 2002; Bekele-Tesemma 2007), so that after DAF/U and DAF/SD degraded into DAF/WG, Olea would have decreased in favour of Rhus. Despite the presence of a new main wood taxon, Olea was still collected and burnt as firewood during Middle and Late Pre-Aksumite times, indicating how valued its wood was.

A different situation can be observed at Ona Adi during the Late Pre-Aksumite phase, when the use of Olea wood seems to have been complemented mainly with Carissa, a DAF/SD genus which also grows on well-drained soils and requires sunlight. The wood selection pattern at Ona Adi remained fairly steady throughout the entire occupation of this Aksumite site, showing a more generalized choice of wood than the community at Mezber. Although the recovery of the DAF/U and DAF/SD vegetation re-established Olea as the preferred firewood, the use of DAF/WG taxa such as Acacia remained fairly constant, and even increased through time, with a corresponding reduction of Carissa. We argue that this trend is associated with the introduction of new selection criteria. These trees provide not only excellent firewood, but are also highly resistant to pest attack (von Maydell 1990; Ruffo et al. 2002). This would have been very useful for an urban site such as Ona Adi, where most of the inhabitants and especially the elites were unlikely to have gathered firewood themselves. Instead, they would have obtained and stored it, as suggested by the presence of wood with fungal damage in the Ona Adi charcoal assemblage, but absent at Mezber. The recorded taxa at Ona Adi mainly
grow locally, so the wood was not obtained from external trade as suggested by Phillipson (2012). Another possible explanation is related to the start of industrial activities at Ona Adi by its Aksumite inhabitants (Phillipson 2012). The wood requirements of a crafting community such as Ona Adi would have been different from those of rural settlements such as Mezber, and differences in wood selection can also be explained by the needs of charcoal making, for example *Acacia* is commonly preferred for this in modern Ethiopia (Bahru et al. 2012; Bekele and Girmay 2014). Large quantities of fuel are needed for industrial activities such as firing pottery or smelting metal, for which suitability of wood for storage is again a crucial factor. Since all analysed samples were retrieved from non-specialized long-term deposits, and no differences by type of context have been found, this question remains unsolved.

### Conclusions

The study of the archaeological charcoal assemblages from Mezber and Ona Adi has revealed insights into the past socio-ecological systems and relationships between people and woodlands in north-eastern Tigray, Ethiopia, during Pre-Aksumite and Aksumite times from the mid 2nd millennium BCE until the late 1st millennium CE. The analyses have recorded the presence of woody taxa related to undifferentiated (DAF/U) and dry-single dominant (DAF/SD) Afromontane forests as well as Afromontane woodlands, wooded grasslands and grasslands (DAF/WG) at both Mezber and Ona Adi. Furthermore, our results show coherence and consistency both within each site and between them. This continuity of plant diversity suggests rather stable local environmental conditions, with no major climatic or environmental changes in this period. Our data also show an important process of woodland loss through human activities around the early to mid 1st millennium BCE. However, this process of landscape degradation does not appear to have been as dramatic as previously suggested by the palaeontological record. We therefore suggest that the current mosaic of microclimates and short distance environmental variation was in existence during the mid 2nd BCE to late 1st millennium CE. Further palaeoecological analyses are needed in order to assemble enough data to allow palaeoenvironmental reconstruction at both local and regional levels.

Our results also suggest that the people of both Mezber and Ona Adi used most of the surrounding habitats, as a wide variety of woody plants were used as fuel. There are, however, some points to be emphasized. On the one hand, the ecological features of the identified taxa suggest that wood collection was mostly carried out in open forests and forest margins. On the other hand, the useful qualities of the wood used suggest selective gathering of wood at both

### Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1007/s00334-021-00825-2.

### Acknowledgements

This research has been done as part of the Eastern Tigray Archaeological Project (ETAP). We are grateful for the participation of the Ethiopian Authority for Research and Conservation of Cultural Heritage (ARCCCH) and the Tigray Tourism and Cultural Commission (TCTB). Many thanks are due to Margareta Tengberg for granting access to wood collections of the Muséum National d’Histoire Naturelle (Paris, France), and especially to the residents of the Gulo Makeda district (Tigray, Ethiopia) for their help, hospitality and participation in all ETAP interviews and excavations. ARG is a member of CaSEs, an excellence group of the Generalitat de Catalunya (SGR-0122) and Unidad Asociada of the Consejo Superior de Investigaciones Científicas (IFC_SIC) and is developing his work within the RAINDROPS Research Project (ERC-Stg2017 G.A. 759800). Financial support was provided by the Social Sciences and Humanities Research Council of Canada (Partnership Grant #890-215-003) and the Ministère de l’Europe et des Affaires étrangères (AVENIR Excellence Grant #901738).

### Data availability

Reference collection is available at https://repositori.upf.edu/handle/10230/43106.

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