CHAPTER 9

The new Garba Guracha palynological sequence: Revision and data expansion

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9.1 SITE DETAILS

In the context of the DFG-funded project ‘Mountain Exile Hypothesis’ (FOR2358) we retrieved a 15.5 m long sediment core from Garba Guracha (GG) (Bale Mountains National Park, Ethiopia – BMNP) during February 2017. A 16,000 year record of 62 pollen samples has been previously produced from GG by Umer *et al.* (2007). In this data paper, we present a new palynological and macrocharcoal record, with 259 pollen and 1301 charcoal samples covering the last 14 ka BP. Previous versions of the charcoal and *Erica* pollen records can be found in Gil-Romera *et al.* (2019). The depth-age model for the presented record in this new manuscript can be found in Bittner *et al.* 2020.

GG is a small (500 × 300 m), 6 m deep lake (6.9°N, 39.9°E), lying in a cirque at 3950 m asl in the BMNP of the Bale-Arsi Massif, Ethiopia (Figure 1). GG sits in a north-facing valley of the Sanetti plateau that was locally glaciated during the Last Glacial Maximum (Ossendorf *et al.* 2019; Tiercelin *et al.* 2008). High seasonality characterizes the rainfall pattern with a dry season from November to February and a bimodal wet season from March to October. Local rainfall patterns in BMNP present an altitudinal (lowlands to highlands) and latitudinal (N to S) increasing rainfall gradient, defining the vegetation zonation (Mieke and Mieke 1994). GG lies between the Ericaceous and afroalpine vegetation belts, however only dispersed *Erica* spp.

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Figure 1. Map of the study area (Bale Mountains National Park) situated east of the Ethiopian Rift Valley in Ethiopia, East Africa (made by Dr. Miguel Sevilla-Callejo). Layout of satellite image is from TerraMetrics© for Google Maps (2019).

stands are present on the south east slopes of the catchment. The dominant plant communities around the lake consist of *Alchemilla haumannii* and *Helichrysum splendidum*-*H. citrispinum* shrublands. The northern lowland area has been heavily transformed by human activities and the natural vegetation remaining are dry afromontane forests dominated by *Podocarpus falcatus* and *Olea europaea* to 2700 m asl, followed by *Myrica salicifolia* and *Dodonaea viscosa* communities that give way at the upper forest limit to *Hagenia abyssinica*-*Juniperus procera* and *Schefflera* spp. communities up to 3200 m asl. *Erica trimera* and *E. arborea*, together with *Hypericum revolutum* form the Ericaceous belt found from 3200 m to 4000 m asl. The southern slopes receive rainfall throughout the year presenting a mixed broadleaved Afromontane rainforest dominated by *Pouteria aidissima*, *Ficus mucoso* but without *Juniperus* (Friis et al. 2010).

9.2 SEDIMENT DESCRIPTION AND METHODS

We retrieved two overlapping cores at 4.8 m water depth with a Livingstone corer from a raft. We obtained sediments to a maximum sediment depth of 1550 cm. Details of core retrieval, sedimentology and lithofacies can be found in Bittner et al. (2020). Charcoal particles and pollen data presented here cover from 13,700 to 94 cal. yr BP, as the bottom most sections were formed by highly inorganic sediments yielding counts too low to be statistically significant. Charcoal was sampled at contiguous intervals (1300 samples, Gil-Romera et al. 2019) and we analysed 259 pollen samples using a modified version of the laboratory protocol of Moore et al. (1994), adding *Lycopodium* spores (Lund University, batch # 1031, 15,636 spores per tablet, SD 592) to estimate concentration and pollen accumulation rates (PAR). A zonation was applied in order to facilitate the pollen data set interpretation. These pollen assemblage zones were done using a CONISS (Grimm 1987) cluster analysis. We calculated the Principal Curve (PrC) for our pollen assemblage to summarize the palynological compositional turnover along one ordination

Figure 2. Age-depth model for Garba Guracha (GG) presenting the prior parameters into the Bayesian framework on the upper panels Modified from Bittner *et al.* (2020).

axis (De'ath 1999). Charcoal and pollen plots and numerical analyses were done using several R packages (R Core Team 2012). Full code, data and further details can be downloaded from Gil-Romera's GitHub repository shorturl.at/rxMW1 and from Neotoma database.

9.3 DATING

The 15.9 ka BP GGU17-1B age-depth model was built combining 48 dated samples using the Bayesian framework of the Bacon package in R (Blaauw and Christen 2011; R Core Team, 2017) (Figure 2). Dates used in this model can be found in supporting online material, and chronological methods are described in Bittner *et al.* (2020).

9.4 INTERPRETATION

We identified 98 taxa and counted an average of 456 pollen grains (SD = 120). We define six pollen zones (GGU1-GGU6) representing the last 13.7 ka BP of vegetation dynamics in GG area (Figure 3).

9.4.1 GGU1 Afroalpine vegetation (1170–1031 cm, 13.7–13 ka BP, 30 pollen samples)

The landscape was dominated by afroalpine vegetation reflecting cool, dry conditions (Figure 3). PAR values indicate a clear expansion of afroalpine and dry forest communities, with a minor development of the Ericaceous belt. At *c.* 13.1 ka BP we identify a large pulse of biomass burning that may be related to local fire activity. However, we cannot discard the possibility that charcoal particles accumulated on a frozen lake surface (Tiercelin *et al.* 2008) prior to the beginning of our record, which were deposited on the lake bottom after the ice melted.

Figure 3. Pollen diagram for lake Garba Guracha at 3950 m asl. Analyst: Graciela Gil-Romera. Vegetation belts are presented in percentages (filled silhouette) and PAR (in bars). Taxa included in each group can be found in the dictionary stored at shorturl.at/rxMW1.

9.4.2 GGU2 Afroalpine-Ericaceous belt turnover (1030–637 cm, 13–8.5 ka BP, 80 pollen samples)

9.4.2.1 GGU 2.1 *Amaranthaceae-Poaceae* dominating (1030–900 cm, 13–11.2 ka BP, 26 pollen samples)

Afroalpine herbs (e.g. *Amaranthaceae*) abruptly decrease at 12.5 ka BP coinciding with Younger Dryas-like conditions (YD). YD conditions have been described in Eastern Africa before (Talbot *et al.* 2007) broadly concurring in time (12.9–11.7 ka BP) with the YD in the Greenland ice cores (GS1, Rasmussen *et al.* 2006). While the YD may not have had a great impact on most lowland African records, afroalpine communities clearly declined, especially the PAR of these communities, except *Artemisia* which does not decrease in abundance. The lower forest seems to expand despite PAR suggesting a poor development. These vegetation dynamics may be pointing to a short and abrupt cold, dry pulse at these altitudes.

9.4.2.2 GGU 2.2 *Expansion of Erica* (899–637 cm, 11.2–8.5 ka BP, 54 pollen samples)

There is a notable expansion of most vegetation communities, as indicated by all PAR values and increased PrC scores. This expansion is especially important in the Ericaceous belt, potentially responding to increasing temperatures and moisture availability linked to the African Humid Period onset (AHP) (deMenocal *et al.* 2000). Under those conditions *Erica* thickets may have fostered biomass burning during the dry season, activating a fire feedback well known in the local modern-day fire ecology (Johansson and Granström 2014). Such a mechanism would explain the Ericaceous PAR variability – that does not always correspond to that of abundance – where expansion events are followed by burning that leads to new resprouting thickets and therefore new biomass to be burnt. In addition, dry forests keep a relatively constant and low presence despite an initial PAR increase, that together with the *Erica* dominance, may suggest the establishment of a wetter and warmer phase during this period. The relative expansion of hydrophytes such as *Cyperaceae* would also indicate higher water availability. From 10 to 8 ka BP *Poaceae* expansion coincides with reduced CHAR and *Erica* PAR indicating a progressive opening of the landscape.

9.4.3 GGU3 Full extension of the Ericaceous belt (636–549 cm, 8.5–7.2 ka BP, 30 pollen samples)

Erica spreads as indicated by its PAR, with a consequential biomass burning and decline in the herbal community while the dry forest boundaries keep similar PAR and abundances. We infer relatively similar climate conditions at this stage, with no clear community transformations as supported by unchanging PrC scores.

9.4.4 GGU4 Ericaceous belt-dry montane forest turnover (548–291 cm 7.2–3.6 ka BP, 52 pollen samples)

9.4.4.1 GGU4.1 *Progressive Erica* decline (547–418 cm, 7.2–5.4 ka BP, 33 pollen samples)

The Ericaceous belt slightly contracts at 7.2 ka BP as the Upper dry forest boundary expands, concurring with increasing biomass burning. The Lower dry forest expands at the end of this zone, while the Ericaceous belt progressively contracts as illustrated by increased PrC scores. The GG landscape may have opened up further as *Erica* cover declines from 6 ka BP onwards, enabling a higher deposition of lowland dry forest pollen taxa, indicating progressively drying conditions.

9.4.4.2 GGU4.2: *Lower dry Afromontane forest* expansion (417–291 cm, 5.4–3.6 ka BP, 19 pollen samples)

The Ericaceous belt and the local biomass burning continue declining while the Lower dry forest boundary, dominated by *Podocarpus* and *Olea*, expands with varying pollen concentrations,

concurring with the spread of *Artemisia* with equivalent values to those of zone GGU2a. This landscape succession suggests drying conditions concurring with the regional AHP termination (de Menocal *et al.* 2000).

9.4.5 GGU5 Upper dry forest expansion, (290–109 cm, 3.6–1 ka BP, 50 pollen samples)

This zone features the constant presence of the dry forest communities, with *Juniperus* dominating until *c.* 2 ka BP. After this *Juniperus* declines in conjunction with new biomass burning and the scarce, consistent presence of ruderals (e.g. *Plantago*) or other herbs in the Afroalpine domain. We hypothesize that this landscape change is likely due to a dry forest upwards shift under similar climate conditions to GGU4b. Increasing human pressure from *c.* 2 ka BP may have triggered more frequent or intense fires to obtain new pastures at the Upper dry forest-Ericaceous Belt limit. The increase in PAR *c.* 2 ka BP in all forest components might be linked to brief climate changes, as increasing temperature or short drought spells (Marshall *et al.* 2009).

9.4.6 GGU6 Upper dry forests and ruderal plants presence (108–60 cm, 1000–94 yr BP, 17 pollen samples)

The last millennium at GG presents a locally open landscape with abundant herbs, especially those indicating human agency (e.g. *Plantago*), with scarce *Erica* presence and an upwards shift of the Upper dry forest. While we cannot discount the possibility of persistent drying conditions and relative temperature changes, we understand landscape changes in this zone to be mainly human-driven.

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