Archaeo-riddle Analysis

Trying methods to improve archaeological inference

Alexes Mes

Department of Archaeology, University of Cambridge

June 2023

1 Research Question

RQ3. What was the rate of dispersal of poppy chewers?

2 Approach

Behind all large-scale human dispersals, such as the spread of the Neolithic in Europe or the Bantu Expansion in sub-Saharan Africa, lies a body of literature seeking to categorise this movement as demic migration vs. acculturation. In the land of Rabbithole we are faced with a similar problem: uncovering the dispersal model of poppy chewers and their farming subsistence strategies amidst a pre-existing hunter-gather population, the rabbit skinners.

One of the standard tools archaeologists use to examine the dominant mechanism of dispersal is the calculation of dispersal rates, typically through regression analyses [1, 2, 3, 4, 5, 6, 7]. The slowest dispersal rates being associated with cultural diffusion (the borrowing of ideas by local populations without any population admixture), while faster rates with demic models (the migration of the social group as a self-contained entity) and the fastest with a mixture of demic and cultural diffusion [8]. Framing dispersal debates as a binary between two forms of movement is restrictive. The reality in any human migration is far more complex: the units of migration (individuals, families, communities), as well as the localised tempo and direction of dispersal frequently shifted [9]. One of the major limitations of regression analyses is that they typically yield a single, global dispersal rate which fails to capture more complex movement dynamics. While there are adaptions that can be used in order to allow for local dynamics – such as Gaussian Process Quantile Regression [10] – these can be prohibitive computationally.

The inverse of asking *How did a cultural trait travel?* is to ask *When did it arrive?* The latter captures the approach to exploring poppy chewer movement used here. Using Bayesian phase models [11, 12, 13, 10], accurate estimates of local arrival times within smaller geographic regions are calculated. A hierarchical structure is introduced into the Bayesian phase model, in order to account for an uneven sampling where some sites contribute multiple radiocarbon dates.

A hierarchical Bayesian phase model defines the calendar date ($\theta_{i,j,k}$) and subsequent observed radiocarbon age ($X_{i,j,k}$) of sample i from site j in region k as

$$\theta_{i,j,k} \sim \mathrm{Unif}\left(\alpha_{j,k},\, \alpha_{j,k} + \delta_{j,k}\right) , \tag{2.1}$$

$$\alpha_{j,k} \sim \mathrm{Unif}\left(a_k,\, b_k\right) , \tag{2.2}$$

$$X_{i,j,k} \sim \mathrm{Normal}\left(f\left(\theta_{i,j,k}\right),\, \sigma_{i,j,k}\right) , \tag{2.3}$$

where $\alpha_{j,k}$ is the arrival time of the phenomenon at site j in region k; a_k is the arrival time of the observed phenomenon in region k; the term $(\alpha_{j,k} + \delta_{j,k})$ is the end date at site j in region k ($\delta_{j,k}$ is understood as the duration of occupation); and b_k is the end date in this region. The measurement uncertainty of $\theta_{i,j,k}$ is accounted for by Eq.(2.3), where $\sigma_{i,j,k}$ is the square root of the sum of the squares of the error on the calibration curve and the sample's ^{14}C age error.

3 Strategy to select additional data

Across Rabbithole, 14 rabbit skinner (hunter gatherer) and 25 poppy chewer (farmer) sites in areas 14, 45, 65, 66, 30 had been identified. Participants were given the ability to survey five additional areas of information. In order to decide on the most interesting regions to survey, a friction calculation was performed. The Rabbithole data provided included elevation and environmental fitness information. This information was used in order to calculate an aggregated fitness, F_k for each region k, assuming initial movement from a putative origin region m:

$$F_k \;=\; d_{m,k} - \omega_f \times f_k + \omega_e \times e_k \,, \tag{3.1}$$

where $d_{m,k}$ is the distance between the centre of the origin region m and the centre of the region of interest k; e_k is the mean elevation in region k and f_k is the mean environmental fitness in each region. The magnitude of the weights (ω_e and ω_f) were chosen to ensure all terms are of the same order of magnitude, while the direction of these weights build in the initial assumptions (i) moving to a lower elevation leads to a decrease in friction and (ii) moving to a higher fitness value leads to a decrease in friction. Note, however, that this was a rough calculation and that there are more sophisticated statistical means of determining the magnitude and direction of these weights.

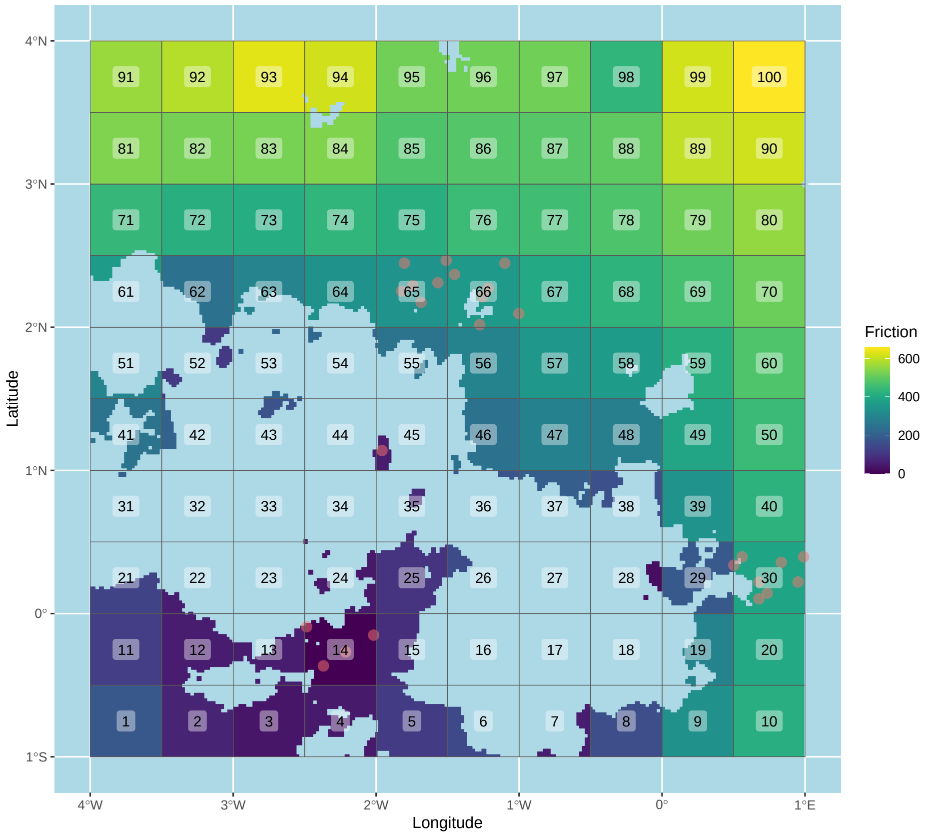

Figure 1: **Aggregated friction**: Aggregated friction, F_k, for each region k in Rabbithole

Examining figure (1), additional information was requested from regions 8, 12, 48, 62, 98. In the final dataset there are 43 poppychewer sites with 206 associated radiocarbon dates and 29 rabbitskinner sites with 60 $C14$ dates.

4 Results

As a first step, a Bayesian quantile regression was performed which yielded a global poppychewer dispersal over the whole of Rabbithole at a rate of 0.9-2.2 km.year^{-1}.

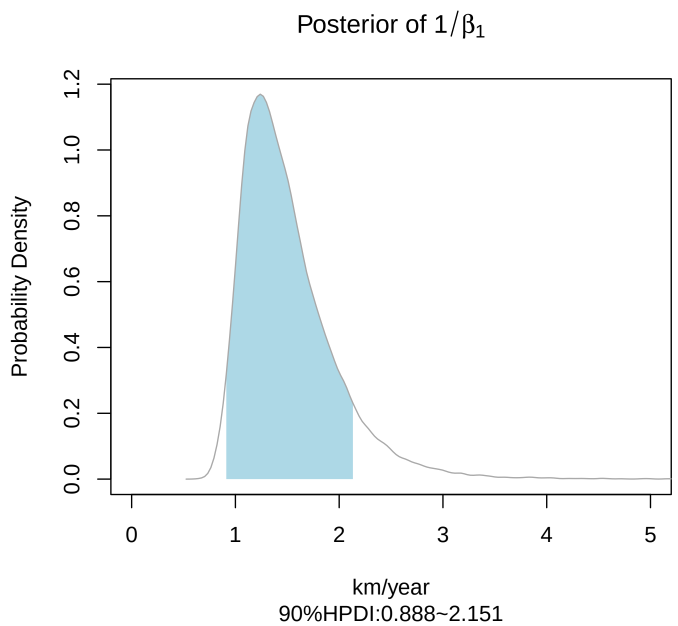

Figure 2: Posterior distribution of the dispersal rate ($1/\beta_1$) for the spread of poppy chewers (and their associated agricultural subsistence strategy) in Rabbithole using Bayesian quantile regression.

As discussed in section (2), in order to examine local dynamics, a hierarchical Bayesian phase model is used. An MCMC analysis was performed over larger spatial regions (diving Rabbithole into 25 areas). The results are given in figures (3) and (4).

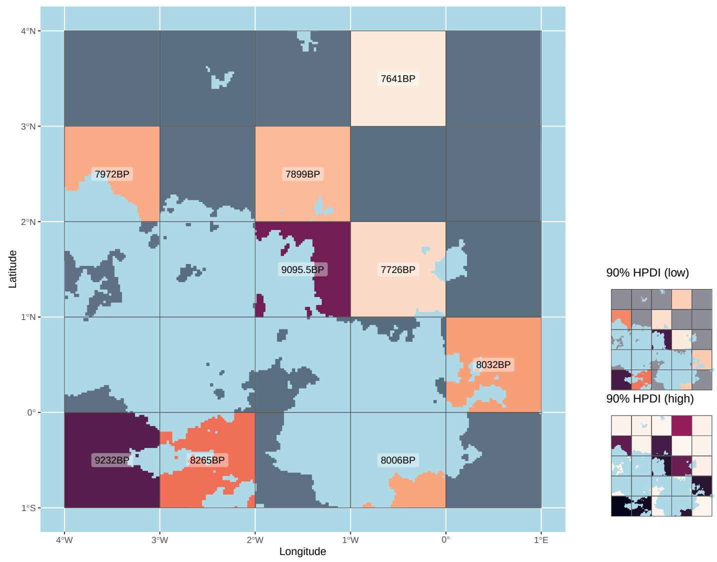

Figure 3: Median arrival times in each region calculated using a hierarchical Bayesian phase model, with low and high bounds of the 90% HPDI indicated in subplots

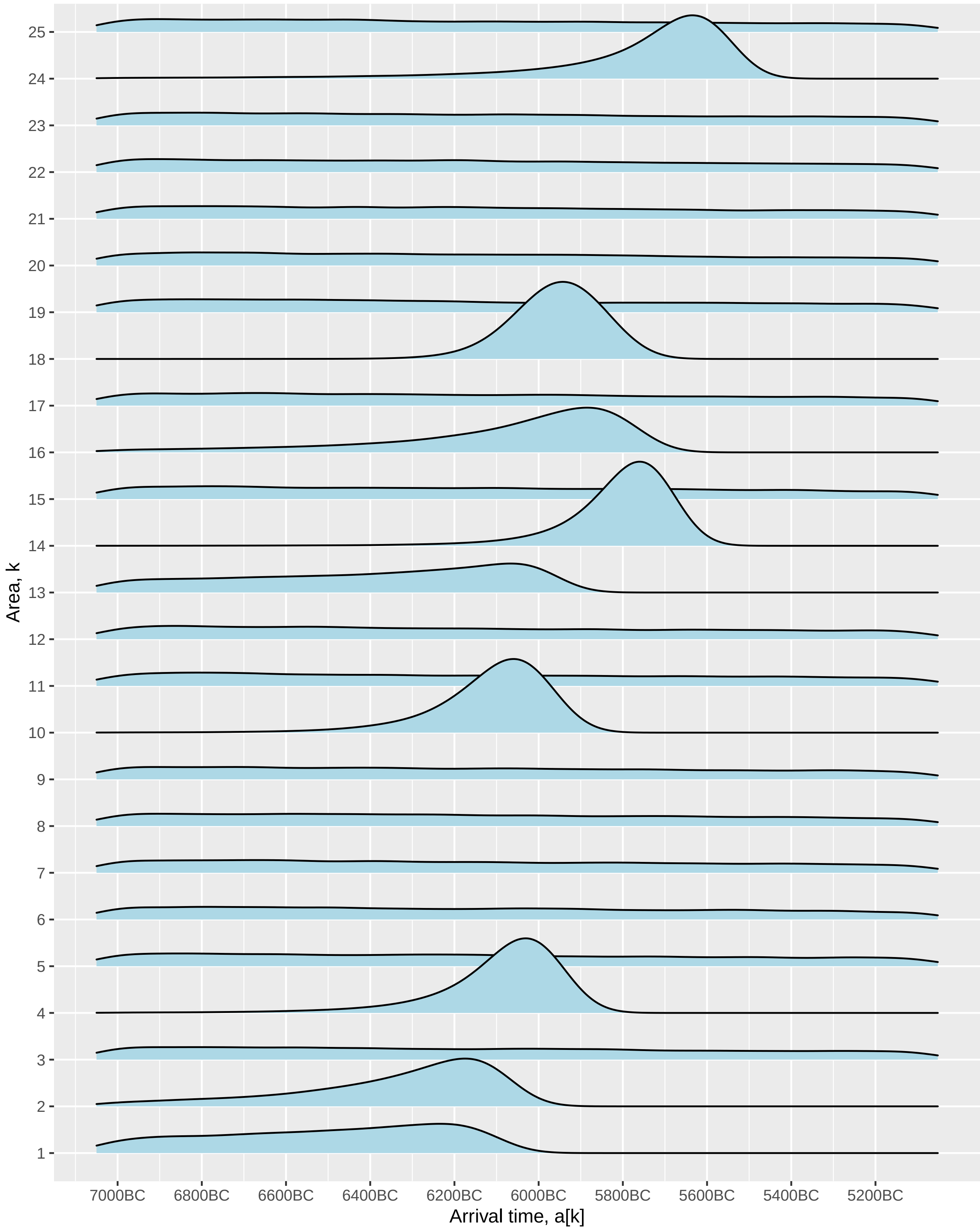

Figure 4: Posterior distribution of arrival times a_k in region k using a hierarchical Bayesian phase model

References

[1] Jean-Pierre Bocquet-Appel, Stephan Naji, Marc Vander Linden, and Janusz K Kozlowski. Detection of diffusion and contact zones of early farming in europe from the space-time distribution of 14c dates. *Journal of Archaeological Science*, 36(3):807–820, 2009.

[2] Marina Gkiasta, Thembi Russell, Stephen Shennan, and James Steele. Neolithic transition in europe: the radiocarbon record revisited. *Antiquity*, 77(295):45–62, 2003.

[3] Ron Pinhasi, Joaquim Fort, and Albert J Ammerman. Tracing the origin and spread of agriculture in europe. *PLoS biology*, 3(12):e410, 2005.

[4] Jacob Van Etten and Robert J Hijmans. A geospatial modelling approach integrating archaeobotany and genetics to trace the origin and dispersal of domesticated plants. *PLoS One*, 5(8):e12060, 2010.

[5] Fabio Silva, Chris J Stevens, Alison Weisskopf, Cristina Castillo, Ling Qin, Andrew Bevan, and Dorian Q Fuller. Modelling the geographical origin of rice cultivation in asia using the rice archaeological database. *PloS one*, 10(9):e0137024, 2015.

[6] Thembi Russell, Fabio Silva, and James Steele. Modelling the Spread of Farming in the Bantu-Speaking Regions of Africa: An Archaeology-Based Phylogeography. *PLOS ONE*, 9(1):e87854, January 2014. Publisher: Public Library of Science.

[7] Neus Isern and Joaquim Fort. Assessing the importance of cultural diffusion in the Bantu spread into south-eastern Africa. *PLOS ONE*, 14(5):e0215573, May 2019. Publisher: Public Library of Science.

[8] Joaquim Fort. Demic and cultural diffusion propagated the neolithic transition across different regions of europe. *Journal of the Royal Society interface*, 12(106):20150166, 2015.

[9] John Robb and Preston Miracle. Beyond migration versus acculturation: new models for the spread of agriculture. In *Proceedings-British Academy*, volume 144, page 99. Oxford University Press Inc., 2007.

[10] Enrico R Crema, Chris J Stevens, and Shinya Shoda. Bayesian analyses of direct radiocarbon dates reveal geographic variations in the rate of rice farming dispersal in prehistoric japan. *Science Advances*, 8(38):eadc9171, 2022.

[11] Dragana Filipović, John Meadows, Marta Dal Corso, Wiebke Kirleis, Almuth Alsleben, Örni Akeret, Felix Bittmann, Giovanna Bosi, Beatrice Ciută, Dagmar Dreslerová, et al. New ams 14c dates track the arrival and spread of broomcorn millet cultivation and agricultural change in prehistoric europe. *Scientific Reports*, 10(1):13698, 2020.

[12] Tengwen Long, Mayke Wagner, and Pavel E Tarasov. A bayesian analysis of radiocarbon dates from prehistoric sites in the haidai region, east china, for evaluation of the archaeological chronology. *Journal of Archaeological Science: Reports*, 12:81–90, 2017.

[13] Christian Leipe, Tengwen Long, Mayke Wagner, Tomasz Goslar, and Pavel E Tarasov. The spread of rice to japan: Insights from bayesian analysis of direct radiocarbon dates and population dynamics in east asia. *Quaternary Science Reviews*, 244:106507, 2020.