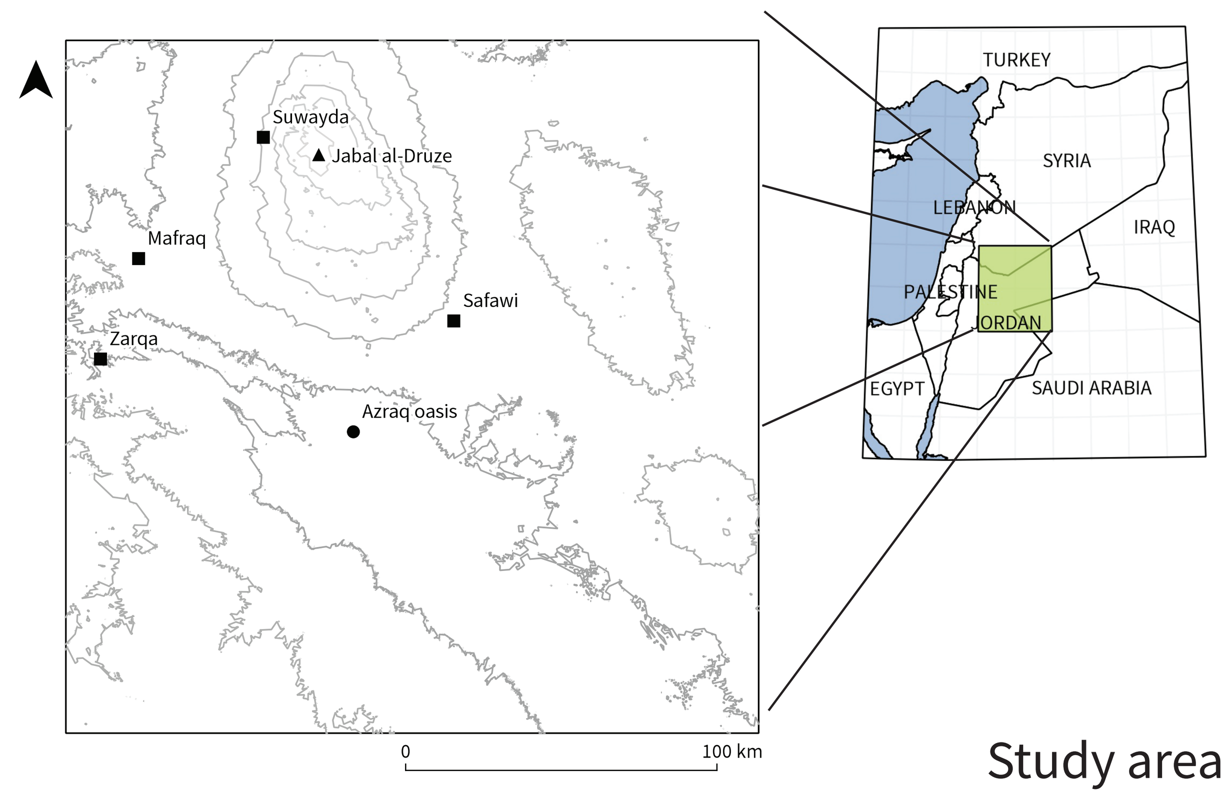
A greener model of palaeoenvironments in the eastern Levant

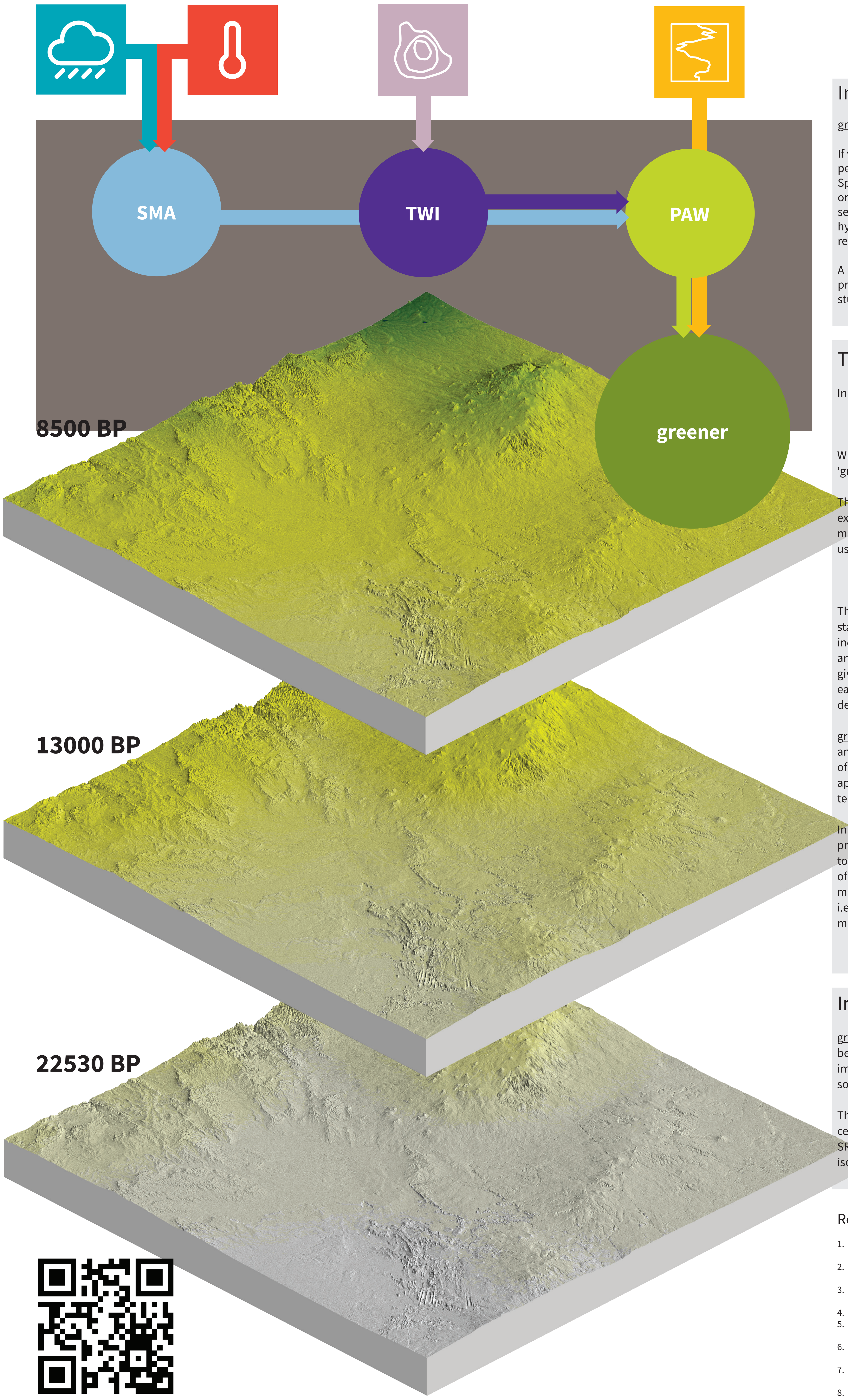
Joe Roe, UCL Institute of Archaeology
<joseph.roe.12@ucl.ac.uk>

UCL

Despite the inhospitality of the landscape today, the arid steppe-deserts of the eastern Levant supported a thriving forager population in prehistory. Palaeoecological research has demonstrated that this occupation was underpinned by the significantly more verdant environments that existed there in the Pleistocene. However, although previous work has yielded detailed reconstructions at particular locales, the broader regional picture remains elusive. greener is a simple model of relative vegetation density ('greenness') aimed at reconstructing regional palaeoenvironments. Although highly idealised and approximate, it is based on widely available geographic, meteorological and palaeoclimatic data, and can be rapidly computed for arbitrary regions and time periods. As such it is well suited to being incorporated into higher level models of plant, animal and human palaeoecology.



Study area
The Azraq Basin, eastern Jordan



https://youtu.be/NXGRb7UIcUw

Inputs

greener requires empirical data in three input variables: rainfall, topography and palaeoclimate.

If we assume that both regional weather patterns and topography have relatively stable over the period of interest, widely available modern data can be used to fulfil the first two requirements. Spatial variation in rainfall can be provided in the form of readily obtained time-averaged rasters or isohyets, or modelled using recent historic data from meteorological databases to incorporate seasonal and interannual variation. A Digital Elevation Model (DEM) is required to model the regional hydrology, which may be a satellite-based global model or locally surveyed depending on the desired resolution.

A palaeoclimate curve is used to add a temporal dimension to the model. This can be any reasonable proxy for palaeorainfall, e.g. lake levels or oxygen isotope ratios from speleothems, available in the study region with a continuous record over the period of interest.

The Model

In its simplest form, the 'greener index' of relative vegetation density (*GI*) is defined as:

$$GI_t = g \cdot c_t$$

Where c_t is the value of a normalized palaeoclimate curve at time step t; and g is some index of 'greenness'.

The model is designed to be flexible, so that different sub-models can be used to calculate g. For example, some applications may find a direct observation of modern vegetation density (e.g. NDVI) more practical than attempting to model it from other data. Here, however, greenness is estimated using a variant of the plant available water index (*PAW*):[1]

$$PAW = ln(a/\tan \beta) \cdot ln(EPREC)$$

The first part of this equation is the topographic wetness index (TWI),[2] a standard hydrological statistic. a is the upstream catchment area of a cell on a raster grid and β is its slope. Essentially, TWI indicates the amount of water that would run through an area of a landscape if it received an even amount of rainfall. To incorporate spatial variation in rainfall, TWI is multiplied by precipitation, giving an index of the soil moisture available to plants in that cell. In an arid environment like the eastern Levant, it is assumed that the availability of water is the major determinant of vegetation density, and therefore PAW is taken to be a reasonable proxy for greenness.

greener's implementation of PAW includes the option to estimate *effective* precipitation (i.e. the amount of moisture actually retained in the soil) using a soil moisture accounting (SMA) model, many of which have been developed by hydrologists.[3] Again, the choice of SMA model will depend on the application: which variables are important to consider in a given environment (e.g. precipitation temperature, ground cover, runoff, etc.) and which of those can be realistically modelled.

In summary, greener combines a topographically-based hydrological model and estimated effective precipitation to calculate an index of the greenness of an area today, then uses a palaeoclimate curve to transform this map based on past conditions. It should be stressed that it is strictly a *relative* index of vegetation density. Calibrating the model in order to predict the absolute values of either past soil moisture or vegetation density is not attempted. Rather, the greenness index is a model of variation; i.e. how verdant an area is likely to be compared to other parts of the study region, and how this might have changed through time.

Implementation

greener was developed as part of my PhD research, to serve as a foundation for models of animal behaviour and human hunting strategies in the eastern Levant, 23,000–8,000 BP. The model was implemented in R[4] using the raster[5] and hydromad[3] packages, and is intended for release as an open source R package.

The results presented here are a preliminary analysis of a subregion of the eastern Levant centred around the Azraq basin in eastern Jordan. It used a 90 m resolution, void-filled and smoothed SRTM2.1 DEM;[6] interpolated average annual precipitation values from 1950-2000;[7] and oxygen isotope ratios from the Soreq cave speleothem in israel as a palaeoclimate proxy.[8]

References

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