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Collins, C, Asouti, E, Grove, M, Kabukcu, C, Bradley, L  and Chiverrell, R (2018) Understanding resource choice at the transition from foraging to farming: An application of palaeodistribution modelling to the Neolithic of the Konya Plain, south-central Anatolia, Turkey. *Journal of Archaeological Science*, 96. pp. 57-72. ISSN 0305-4403

**DOI:** <https://doi.org/10.1016/j.jas.2018.02.003>

**Publisher:** Elsevier

**Version:** Accepted Version

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1 Title:

2 **Understanding resource choice at the transition from foraging to farming: An**  
3 **application of palaeodistribution modelling to the Neolithic of the Konya Plain, south-central**  
4 **Anatolia, Turkey**

5

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35 **Understanding Resource Choice at the transition from foraging to farming: An**  
36 **application of palaeodistribution modelling to the Neolithic of the Konya plain, south-**  
37 **central Anatolia, Turkey**

38

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49

50 **Abstract**

51 The role of the environment in shaping agricultural origins is still not fully understood,  
52 despite a century of debate on this topic. Comparison of the expected prevalence of a  
53 resource in the landscape with actual archaeological presence of the same resource can  
54 provide a metric for assessing resource choice in prehistory. However, the  
55 palaeoenvironmental data that would allow resource choice to be evaluated in this way are  
56 rarely available. Species Distribution Modelling (SDM) techniques allow independent  
57 palaeoenvironmental datasets to be computed, which when compared to actual species'  
58 presence at sites as attested by archaeological datasets, can provide data on resource choice.  
59 Following recent calls for SDM to be applied more widely in archaeological contexts, we  
60 outline a simple method for predicting the presence of plant species in prehistory using  
61 modern analogues and palaeoclimatic datasets. These modelled distributions provide an  
62 independent dataset for comparison with archaeological data, thus providing a window into  
63 human resource choice in prehistory. We outline the method with specific reference to the  
64 transition from foraging to farming in the Neolithic of Central Anatolia, but the method could  
65 be applied to any period or region. We have used exclusively open source data and provided  
66 all code in our online supplementary materials, so that our method can be utilized by  
67 researchers interested in human resource choice in any region of the world and any period.

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68 **Keywords:** Neolithic; Turkey; Agriculture; GIS; Palaeodistribution modelling;  
69 Palaeoenvironment

70

## 71 **1. Introduction**

72 Palaeoenvironmental reconstruction, as practiced within archaeological contexts,  
73 typically assumes that palaeoecological assemblages are representative of the landscape and  
74 climate in which they were deposited. This is the case whether it is the climate or the local  
75 vegetation that is being reconstructed. A common approach to quantifying past climate  
76 variables from pollen cores is to identify modern analogue counterparts for identified fossil  
77 taxa, taking the overlapping range of these species' modern tolerances as the likely past  
78 climate range at the site of interest (Guiot, 1990). This method has been widely applied to a  
79 variety of Pleistocene and Holocene pollen assemblages, both for regional climate  
80 reconstruction (e.g., Cheddadi et al., 1998) and at the continental scale (e.g., Davis et al.,  
81 2003). Similarly, where the object of palaeoenvironmental reconstruction is the vegetation  
82 history of a particular landscape, the pollen or macro-charcoal assemblages are assumed to be  
83 representative of the palaeolandscape subject to an evaluation of their taphonomic histories  
84 (e.g., Bottema and Woldring, 1984; Chabal et al., 1999).

85 Such approaches to palaeoenvironmental reconstruction have several shortcomings,  
86 with most palaeoenvironmental datasets being subject to biases. In the case of pollen  
87 assemblages, both differential dispersal and preservation can skew the datasets (Campbell,  
88 1999). Anthracological and faunal assemblages suffer from similar biases in addition to being  
89 further skewed by human resource choice, as humans practice selective foraging in the  
90 surrounding habitat; available floral and faunal species will not be uniformly selected, and  
91 thus will not form a true representation of the available resources (Asouti and Austin, 2005;  
92 Picornell et al., 2011).

93 While these biases can be problematic for palaeoenvironmental reconstructions, they  
94 are potentially useful for archaeological interpretation; any discrepancy between these  
95 assemblages and the actual expected distribution of resources in the landscape will provide a  
96 window into human resource choice in prehistory. To compare the distribution of flora and  
97 fauna in a prehistoric landscape with their presence in archaeological assemblages, an  
98 independent record of their presence is required; a record that does not originate directly from  
99 the archaeological data. Such an independent record can be obtained using Species

100 Distribution Modelling (SDM) (for an overview see Elith and Leathwick, 2009) an approach  
101 that is theoretically opposed to traditional palaeoenvironmental reconstruction methods.  
102 While palaeoenvironmental modelling through the ‘Mutual Climatic Range’ method (Pross et  
103 al., 2000) uses the climatic range of modern analogue species to infer the climate of a given  
104 site in the past, SDM typically utilizes independent palaeoclimatic models or data to hind cast  
105 the presence of a species in prehistory, based on the same observed climatic range of modern  
106 analogue species (Franklin, 1995; Svenning et al., 2011). Furthermore, there is no *a priori*  
107 reason to believe that there are true modern analogues for prehistoric environments. SDM  
108 avoids this problem by treating each species separately and reconstructing prehistoric guilds  
109 from the bottom up (Svenning et al., 2011).

110         Following recent calls for SDM to be more widely applied in archaeology and  
111 palaeoanthropology (Franklin et al., 2015), we present a comprehensive example of the  
112 method as applied to the Neolithic of the Konya plain, in central Anatolia, Turkey, a study  
113 region and period of great archaeological and palaeoecological interest for understanding the  
114 origin of agriculture in Southwest Asia and its subsequent spread into Europe (cf. Roberts et  
115 al., 2001; Asouti, 2006). In addition to providing a pertinent example of SDM as applied to  
116 an archaeological context, we also illustrate how SDM can provide the independent  
117 palaeoenvironmental reconstruction that is required if we are to obtain meaningful insights  
118 into the nature of human resource choice in prehistory.

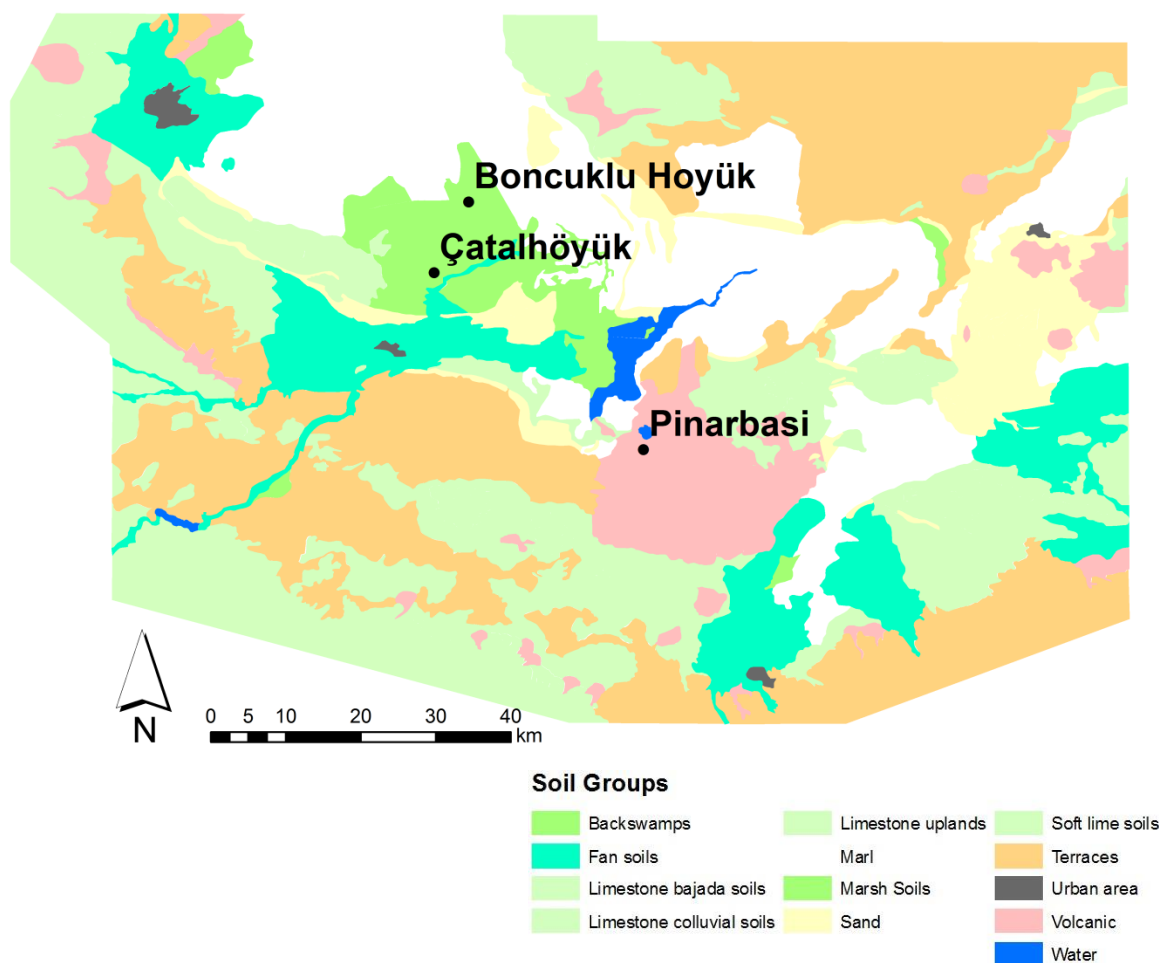
119

## 120 **2. The regional geographical and archaeological setting**

121         The Konya basin is an endoreic, high-altitude (~1000 m a.s.l.) intramontane steppe  
122 plateau. The climate today is continental semi-arid, and the landscape has been heavily  
123 irrigated for farmland. In the recent past the plain was noted for its extensive marshlands,  
124 lakes, and seasonal water bodies (de Meester, 1970) which have largely disappeared within  
125 the past thirty years (Asouti and Kabukcu, 2014). A large palaeolake covered much of the  
126 plateau in the late Pleistocene, which dried up around 17,000 BP leaving large areas of marl  
127 across its former range (Roberts et al., 1999).

128         As an early locus of Neolithic communities outside the Fertile Crescent, the Konya  
129 Plain represents a key archaeological landscape for understanding the spread of early food  
130 production and Neolithic lifeways into central and western Anatolia and southeast Europe.  
131 The transition from foraging, through to cultivator-forager and farming economies (~15,000-

132 9000 cal BP) can be traced through the local prehistoric archaeological sequence (Baird,  
133 2012; Baird et al., 2012, 2013; see also Fig. 1). The rock-shelter and open-air sites of  
134 Pınarbaşı, at the foothills of the volcanic massif of Karadağ, on the shores of the Hotamış  
135 depression were the focus of prehistoric occupation from the end of the Pleistocene through  
136 to the 11<sup>th</sup> millennium cal BP, including a late phase of pastoral campsite activity dating from  
137 the 9<sup>th</sup> millennium cal BP (Baird et al., 2011, 2013). With regard to the Neolithic period (11<sup>th</sup>-  
138 9<sup>th</sup> millennia cal BP) the available archaeobotanical datasets indicate that neither  
139 domesticated crops nor their wild progenitors were present at Pınarbaşı (Fairbairn et al.,  
140 2014). Boncuklu höyük (8300-7500 cal BC (Baird, per comm, 2018) is a small Neolithic tell  
141 site to the northwest of Pınarbaşı, with evidence for year-round settlement and a local  
142 economy heavily reliant on hunting with some evidence for the local adoption of some  
143 domesticated crops (Baird, 2012). At the much larger Neolithic site of Çatalhöyük East, ~8.5  
144 km to the southwest of Boncuklu, mixed agropastoral production, based on crop cultivation  
145 and caprine herding, formed the mainstay of the local economy throughout its long habitation  
146 history (~9100-8000 cal BP) (cf. Hodder, 2007; Bogaard et al., 2013).



**Figure 1:** Map of the major modern landscape units of the Konya basin (modified after de Meester, 1970). The locations of key archaeological sites mentioned in the text are shown.

### 3. Material and methods

#### 3.1 Species Distribution Modelling (SDM) method

SDM represents a powerful tool for approaching palaeoenvironmental reconstruction in the context of prehistoric archaeology, due to its independently produced projections of past resource distributions which, when compared to zooarchaeological, anthracological and archaeobotanical datasets, permit archaeologists to obtain unique insights into past human resource choice (Franklin et al., 2015). Species included in SDM were selected based on their relevance to the geographic region (see also Table 1). We used locality data from the Global Biodiversity Information Facility (GBIF) ([www.gbif.org](http://www.gbif.org)), querying the database for each species of interest by species name. We obtained modern climate data from worldclim.org (Hijmans et al, 2005), elevation data for Turkey at 90m resolution from the

164 SRTM (Shuttle Radar topography mission) (Jarvis et al, 2006; <http://srtm.csi.cgiar.org>), and  
 165 global elevation data at 5 minute resolution from Terrain BASE (  
 166 [ftp://ftp.ngdc.noaa.gov/Solid\\_Earth/cdroms/TerrainBase\\_94/data/global/tbase/tbase.txt](ftp://ftp.ngdc.noaa.gov/Solid_Earth/cdroms/TerrainBase_94/data/global/tbase/tbase.txt) ). For  
 167 each species of interest, modern presence data (MPD) were downloaded from the GBIF.  
 168 Species MPD were then clipped to a geographical range encompassing the Mediterranean,  
 169 Southern, Central and Western Europe and the Near East. This geographical range (Fig. 2)  
 170 was selected to exclude any samples held in artificial research environments, outside of their  
 171 potential natural environmental ranges. A minimum of 50 locality samples were obtained for  
 172 each species of interest; where the GBIF sample size was insufficient, we supplemented plant  
 173 species data from additional sources such as the *Flora of Turkey* (Davis, 1965).

174  
 175 Modern mean monthly temperature and mean monthly precipitation layers were  
 176 obtained from worldclim.org. Mean monthly temperature layers were used to compute the  
 177 variable of *Effective Temperature* (ET – equation 1) which incorporates the temperatures of  
 178 both the mean warmest month and the mean coldest month and relates to the length of the  
 179 plant growing season (Bailey, 1960).

180

$$181 \quad ET = \left[ (18 \times MWM) - \frac{(10 \times MCM)}{(MWM - MCM)} + 8 \right]$$

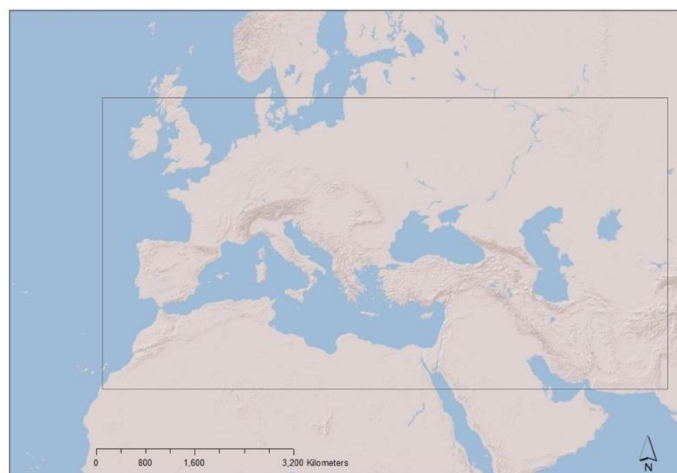
182

183 Mean annual precipitation was also computed from the monthly data. In addition to these  
 184 climatic layers, an additional global elevation layer was incorporated into the analysis, used  
 185 as a proxy for ‘frost days’, which we found in preliminary runs to be a useful predictor of the  
 186 occurrence for plant species in the semi-arid, continental climate regime characterising the  
 187 Konya plain. ‘Frost days’ have featured in combination with other geographic variables in  
 188 several predictive modelling studies, and have been shown to successfully predict the  
 189 distribution of several plant and animal species (e.g., Castro et al., 2008). Frost days have  
 190 been shown to be a limiting factor in the distribution of beech trees in Europe (Bolte et al.,  
 191 2007).

192 Presence point data for each species of interest were overlaid onto the three abiotic  
 193 layers of ET, annual precipitation, and elevation, which were then sampled at these locations.  
 194 We explored the empirical univariate distribution of these variables for several plant species  
 195 and found that in most cases these variables were normally distributed, as we would expect  
 196 following Shelford’s law of tolerance (Shelford, 1931). The resulting multivariate distribution



197 was interpreted as the *fundamental niche* of each species. The fundamental niche of a species  
 198 corresponds to the multidimensional realm that it could potentially inhabit (Hutchinson,  
 199 1957). However, the fundamental niche is rarely realized, due to the impacts of historical or  
 200 anthropogenic factors. Instead, most species' distributions will represent their *realized niche*;  
 201 i.e., a smaller subset of the range that could be occupied by a species in the absence of  
 202 competition or human intervention. Natural barriers are also likely to limit the actual  
 203 dispersal of a species, hence also contributing to the ultimate shape of the realized niche.



*Figure 2: Outline of the study region: locality samples were obtained from within the delimited range.*

204 Inevitably, the modern presence data used in this study are drawn from the realized niche of  
 205 each species. Since the modelled distribution based on this sample cannot take account of any  
 206 historical or competitive factors that will limit species distributions, it represents an  
 207 approximation of the fundamental niche, termed the *Projected Fundamental Niche* (PFN). It  
 208 must be noted that it is possible that species' niches might have changed from the early  
 209 Holocene to the present day, although given the relatively limited time depth it seems  
 210 unlikely that any such changes might have impacted significantly the modelling of PFNs.

211 Unlike traditional palaeoenvironmental modelling, which draws on mutual climatic  
 212 ranges, SDM requires palaeoclimatic data as an input. Palaeoclimatic records from Anatolia  
 213 have indicated a rapid increase in humidity with the onset of the Holocene, as evidenced in  
 214 stable isotope and pollen from Lake Van in eastern Anatolia (Wick et al., 2003). Analysis of  
 215 speleothems from Southwest Asia also point to an increase in moisture at the onset of the  
 216 Holocene, with higher values suggested by comparison to both the Younger Dryas and the  
 217 present-day (Göktürk et al., 2011; Orland et al., 2012). However, such speleothem and  
 218 isotope sequences only inform us about *relative* changes in precipitation, temperature and

219 seasonality, and cannot be readily translated into absolute temperature and precipitation  
220 values (see also Jones et al., 2007). Equally while climate models also provide high temporal  
221 resolution time-slices for the Holocene (e.g., Braconnot et al., 2007) these are frequently  
222 characterised by low spatial resolution. Thus, for the present study species distributions were  
223 modelled for a low-resolution sequence comprising just two phases: an early Holocene and a  
224 late Holocene phase. Temperature and precipitation changes from the present to the early and  
225 the late Holocene were based on estimates provided for the neighbouring region of  
226 Cappadocia in central Anatolia by Jones et al. (2007) based on hydrological and oxygen  
227 stable isotope mass balance models. We used the difference between the modern and Early  
228 Holocene average annual temperature and annual precipitation for Cappadocia to obtain a  
229 transformation that could be used to convert the modern ET and precipitation layers into early  
230 Holocene layers, through addition or subtraction at each pixel. This approach assumes that  
231 temperature and precipitation in Central Anatolia has altered in a uniform manner across  
232 space, which while almost certainly a simplification of the actual pattern of climate change in  
233 the region, is the closest we can come to obtaining absolute values for temperature and  
234 precipitation for Konya as most palaeoclimatic archives available for the Konya region  
235 provide only relative climatic data.

236 Individual species distribution models were produced for all plant and animal species  
237 in the manner outlined above and summary statistics (mean and standard deviation) were  
238 collected. **Table 1** shows the number of specimens for each species within the study region.  
239 All locality data were derived from the GBIF, with some exceptions. Additional *Juniperus*  
240 *excelsa* data were derived from *The Flora of Turkey* (Davis, 1965), and *The Atlas of the*  
241 *World's Conifers* (Farjon and Filer, 2013). *Quercus cerris*, *Q. pubescens* and *Populus*  
242 *tremula* data are derived from the *Flora of Turkey* (Davis, 1965). *Crataegus orientalis* is a  
243 composite of data from the GBIF and the *Flora of Turkey*. *Amygdalus orientalis* data were  
244 derived from the *Flora of Turkey*, and Browicz and Zohary (1996) while *Celtis tournefortii*  
245 data were derived from the GBIF (*C. glabrata* and *C. tournefortii*), the Turkish Plants Data  
246 Service ([www.tubives.com](http://www.tubives.com)) and *Flora Europaea* (Tutin et al, 2010). *Carex divisa* locality  
247 data from the GBIF. *Lens culinaris ssp. orientalis* data were derived from the GBIF and the  
248 *Flora of Turkey*. Lastly, due to the low number of available sample points, the geographic  
249 range of *Tamarix parviflora* was extended slightly outside the limits of the study region to  
250 reach the minimum requirement of 50 samples. Where samples exceeded 3000 data points, a  
251 random sub-sample of 3000 points was taken.

252

253 **Table 1:** Plant species used in the study and number of sample points

| <b>Plant species</b>                             | <b>N of sample points</b> |
|--|---------------------------|
| <i>Quercus cerris</i>                            | 113                       |
| <i>Quercus pubescens</i>                         | 99                        |
| <i>Populus tremula</i>                           | 172                       |
| <i>Juniperus excelsa</i>                         | 72                        |
| <i>Celtis tournefortii</i>                       | 59                        |
| <i>Amygdalus orientalis</i>                      | 112                       |
| <i>Fraxinus angustifolia</i>                     | 1245                      |
| <i>Tamarix parviflora</i>                        | 104                       |
| <i>Ficus carica</i>                              | 2896                      |
| <i>Ulmus minor</i>                               | 3000                      |
| <i>Salix alba</i>                                | 3000                      |
| <i>Pistacia atlantica</i>                        | 530                       |
| <i>Pistacia terebinthus</i>                      | 1375                      |
| <i>Crataegus orientalis</i>                      | 76                        |
| <i>Acer monspessulanum</i>                       | 583                       |
| <i>Hordeum vulgare</i> ssp. <i>spontaneum</i>    | 540                       |
| <i>Bolboschoenus glaucus</i>                     | 183                       |
| <i>Aegilops neglecta</i>                         | 742                       |
| <i>Aeluropus littoralis</i>                      | 242                       |
| <i>Bromus arvensis</i>                           | 2689                      |
| <i>Carex divisa</i>                              | 1771                      |
| <i>Festuca ovina</i>                             | 2999                      |
| <i>Hordeum bulbosum</i>                          | 1208                      |
| <i>Stipa holosericea</i>                         | 71                        |
| <i>Triticum turgidum</i> ssp. <i>dicoccoides</i> | 155                       |
| <i>Triticum monococcum</i> ssp. <i>boeoticum</i> | 224                       |
| <i>Chenopodium album</i>                         | 3000                      |
| <i>Lens culinaris</i> ssp. <i>orientalis</i>     | 51                        |
| <i>Cicer reticulatum</i>                         | 77                        |
| <i>Pisum sativum</i> ssp. <i>elatius</i>         | 217                       |
| <i>Vicia ervilia</i>                             | 942                       |
| <i>Artemisia herba-alba</i>                      | 2751                      |

254

255 In addition to modelling the vegetation based on their observed ET, precipitation and  
256 elevation, we included soil types as a factor in the model. The extensive Konya plain soil  
257 survey conducted by de Meester (1970) provided the basis for this and we have used this soil  
258 map as a layer in our model. Soil-vegetation compatibility was determined based on  
259 ecological factors including species autecology alongside historical and modern fieldwork  
260 data (see overview in Asouti and Kabukcu, 2014) and incompatible soils were then ‘switched  
261 off’ in the model, so that a patch featuring an incompatible soil is always given a PFN of 0.  
262 Compatible soils for each modelled plant species are shown in Table 1. The PFN varies

263 spatially, as it is dependent on the geographic input layers (eg ET, precipitation). We refer to  
 264 the spatially varying field of PFN values as the ‘PFN surface’.

265

266 **Table 2:** Plant species and compatible soil types

| <b>Plant species</b>                             | <b>Compatible soil type</b>                   |
|--|---|
| <i>Quercus cerris</i>                            | Limestone, terraces, volcanic                 |
| <i>Quercus pubescens</i>                         | Limestone, terraces, volcanic                 |
| <i>Populus tremula</i>                           | “Backswamp”                                   |
| <i>Juniperus excelsa</i>                         | Limestone, terraces                           |
| <i>Celtis tournefortii</i>                       | Limestone, fan soils, terraces, volcanic      |
| <i>Amygdalus orientalis</i>                      | Limestone, fan soils, terraces, volcanic      |
| <i>Fraxinus angustifolia</i>                     | Fan soils, terraces                           |
| <i>Tamarix parviflora</i>                        | “Backswamp”, fan soils                        |
| <i>Ficus carica</i>                              | Fan soils, terraces                           |
| <i>Ulmus minor</i>                               | Fan soils, terraces                           |
| <i>Salix alba</i>                                | “Backswamp”                                   |
| <i>Pistacia atlantica</i>                        | Limestone, terraces, volcanic                 |
| <i>Pistacia terebinthus</i>                      | Limestone, terraces, volcanic                 |
| <i>Crataegus orientalis</i>                      | Limestone, fan soils, terraces, volcanic      |
| <i>Acer monspessulanum</i>                       | Limestone, fan soils, terraces                |
| <i>Hordeum vulgare</i> ssp. <i>spontaneum</i>    | Limestone, fan soils, terraces, volcanic      |
| <i>Bolboschoenus glaucus</i>                     | “Backswamp”                                   |
| <i>Aegilops neglecta</i>                         | Terraces, marl, volcanic                      |
| <i>Aeluropus litoralis</i>                       | “Backswamp”                                   |
| <i>Bromus arvensis</i>                           | Terraces, marl, volcanic                      |
| <i>Carex divisa</i>                              | “Backswamp”, fan soils                        |
| <i>Festuca ovina</i>                             | Terraces, marl, sand, volcanic                |
| <i>Hordeum bulbosum</i>                          | Terraces, volcanic                            |
| <i>Stipa holosericea</i>                         | Terraces, marl, volcanic                      |
| <i>Triticum turgidum</i> ssp. <i>dicoccoides</i> | Limestone, terraces, volcanic                 |
| <i>Triticum monococcum</i> ssp. <i>boeoticum</i> | Limestone, terraces, volcanic                 |
| <i>Chenopodium album</i>                         | “Backswamp”, marl, sand, alluvial sandy loams |
| <i>Lens culinaris</i> ssp. <i>orientalis</i>     | Limestone, terraces, volcanic                 |
| <i>Cicer reticulatum</i>                         | Limestone, terraces, volcanic                 |
| <i>Pisum sativum</i> ssp. <i>elatius</i>         | Limestone, terraces, volcanic                 |
| <i>Vicia ervilia</i>                             | Limestone, terraces, volcanic                 |
| <i>Artemisia herba-alba</i>                      | Sand, marl                                    |

267

### 268 3.1.1 Testing the models

269 As a test of the strength of the PFN, we removed a sample of 10% of datapoints for each  
 270 species. We then recalculated the PFN based on the 90% of remaining datapoints. We then  
 271 overlaid the excluded 10% of datapoints onto the PFN surface for that species, and sampled  
 272 the PFN at these locations. This is similar to the approach to testing SDMs advocated by  
 273 Copeland et al (2016).

274 Testing the model in this way enables us to say how likely the model is to predict the  
275 presence of a species in a location where we know it to be present. However, due to the  
276 nature of the samples, we are unable to say how likely the model is to predict the presence of  
277 a species where it is *not* found. This is because we cannot say with any certain whether a  
278 particular species is definitively *not* found in any location, even where it is not present in the  
279 sample database at a location.

280 The results of the model tests for individual species are tabulated in the supplementary  
281 materials. Species are more likely to be present in a location where a high PFN is produced  
282 from the model. Therefore, in the test cases, species with the highest average PFN at  
283 locations where we know they are found, are species for which the models most accurately  
284 predict the presence of the species.

285

286

### 287 *3.2 Site Catchment Analysis method*

288 The Site Catchment Analysis method was introduced into archaeology through the  
289 work of Vita-Finzi and Higgs (1970) at Mount Carmel, Palestine. The method allows the  
290 relationship between the site and the wider environment to be understood, through mapping  
291 the site within the surrounding area and the resources found within this area. They reasoned  
292 that in general resources located further away from a site would be exploited less frequently  
293 than resources found immediately adjacent to the site, and they used an ethnographically-  
294 derived distance of 10 km to represent a feasible distance from the site which hunter-  
295 gatherers would be prepared to regularly travel. The method has been critiqued and  
296 developed since the work of Vita-Finzi and Higgs (1970). Notably, their study has been  
297 criticised for relying on modern land use patterns to obtain data on past environmental  
298 conditions (Hodder and Orton, 1979). Likewise, the development of Least Cost Path  
299 approaches have built on the SCA method while incorporating more complex approaches to  
300 modelling human movement in the landscape, considering factors such as elevation, slope,  
301 terrain, and river systems (Surface-Evans and White, 2012).

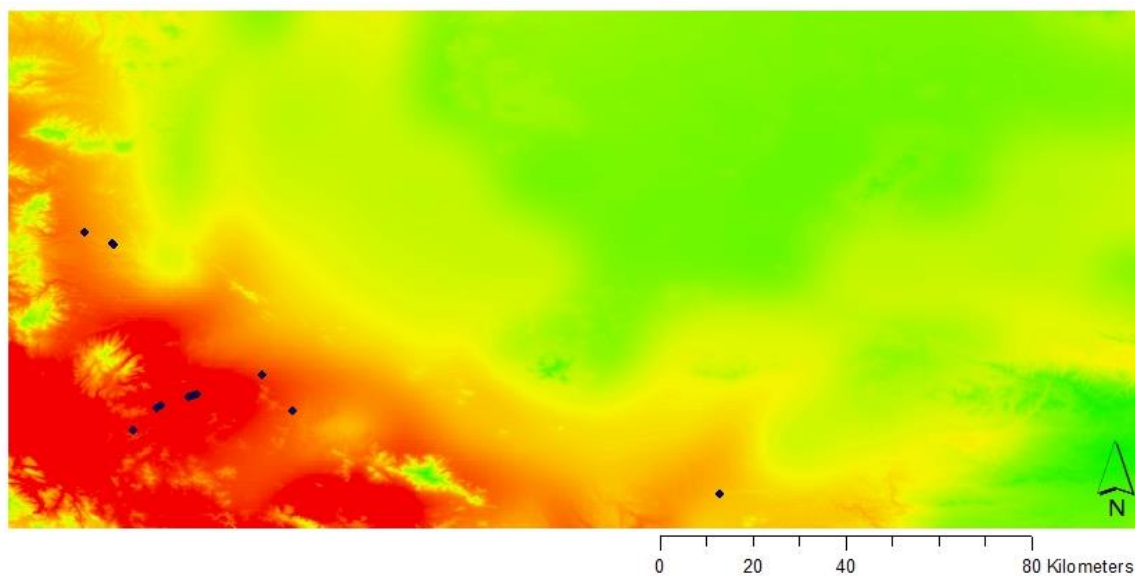
302 Given that our method here is based on modelled PFN surfaces, we can overcome  
303 some of the issues of assuming modern land use and environmental patterns are analogous to  
304 the past. However, our results are influenced by modern data on the environment, in the form  
305 of the soil map produced by de Meester (1970). The approach that we have taken with  
306 producing the SCA model combines the effects of the distance from site with the perceived

307 utility of each patch. Three layers are required to create the SCA: a layer containing the  
 308 distance from the site, the PFN surface, and a further ‘discounted PFN surface’, calculated by  
 309  $[(PFN) - (\text{distance from site})]$ . Discounted PFN surfaces are restricted to a 10km radius of  
 310 each site; this distance is ethnographically derived by Lee (1969), and widely used to  
 311 approximate a two hour walk by hunter-gatherers in search of resources.

312

#### 313 4. Results

314 Individual layers were produced, modelling the PFN surface for each plant species  
 315 across the two phases (early and late Holocene). In general, there was good agreement  
 316 between PFNs for the late Holocene and independent historical and fieldwork observations of  
 317 species distributions in the Konya plain area. As an example, **Figure 3** shows the PFN for



*Figure 3: PFN values for Juniperus excelsa with observation points mapped on derived from Asouti and Kabukcu (2014)*

318 *Juniperus excelsa* with observation points derived by Asouti and Kabukcu (2014) mapped on;  
 319 all observation points occur in locations where there is a high (red) or moderate (amber)  
 320 value for the PFN. The PFN is a number scaled between 0 and 1 which represents the  
 321 likelihood of the species being found at a particular location.

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324 After modelling the PFN for each species of interest, we collected summary statistics  
 325 for individual layers; the maximum and mean pixel values for the plain. The distributions of  
 326 species per these values are shown in the graphs below, with species organised into trees,

327 grasses, and miscellaneous (shrubs, herbs). The individual modelled PFN surfaces for every  
 328 species of interest can be found in the online supplementary materials, along with the python  
 329 code used to generate these PFN surfaces in ArcMap. Any researcher can use this code, along  
 330 with the open source palaeoclimatic data provided by worldclim.org, to model predicted  
 331 species abundance in their period and location of interest.

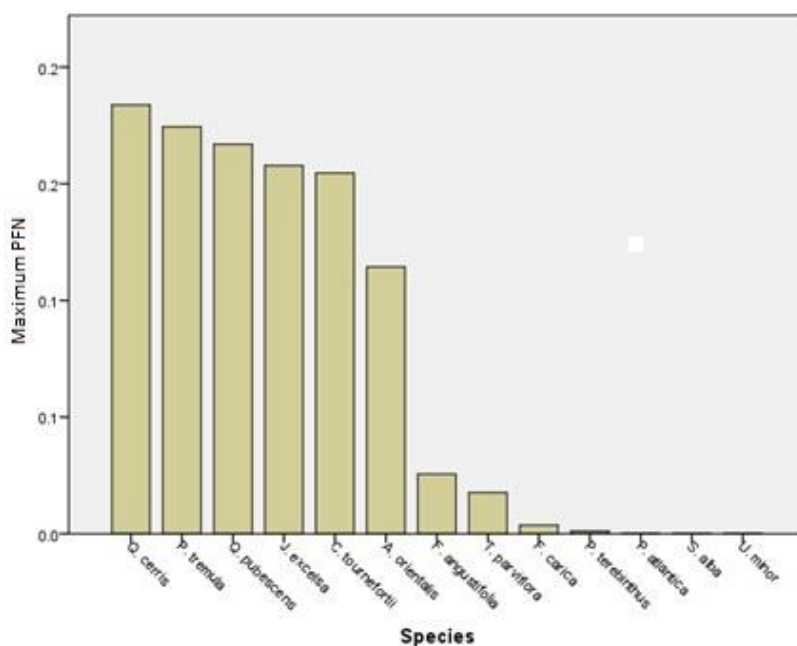
332 Many results are shown grouped according to the ‘predicted relative abundance’ of the  
 333 PFNs. For example, Figure 5, shows the distribution of the floral species in the vicinity of  
 334 Boncuklu according to the average PFN value, standardized so that all of the species’ ‘predicted  
 335 relative abundance’ sum to 1. These predicted relative abundances can therefore be treated as  
 336 indicative of the frequency distributions of species within the area represented.

#### 337 4.1 Early Holocene Phase Results – Trees

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##### 339 4.1.1. Maximum PFN, standardized, for all modelled tree species, across the Early 340 Holocene Konya Plain

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*Figure 4: Distribution of modelled tree species Konya Plain. The Maximum PFN for each tree species, across the whole of the Early Holocene Konya Plain, is shown.*

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347 4.1.2 Site Catchment Models (SCM): Distribution of trees within 10km radius of Early  
 348 Holocene Boncuklu  
 349

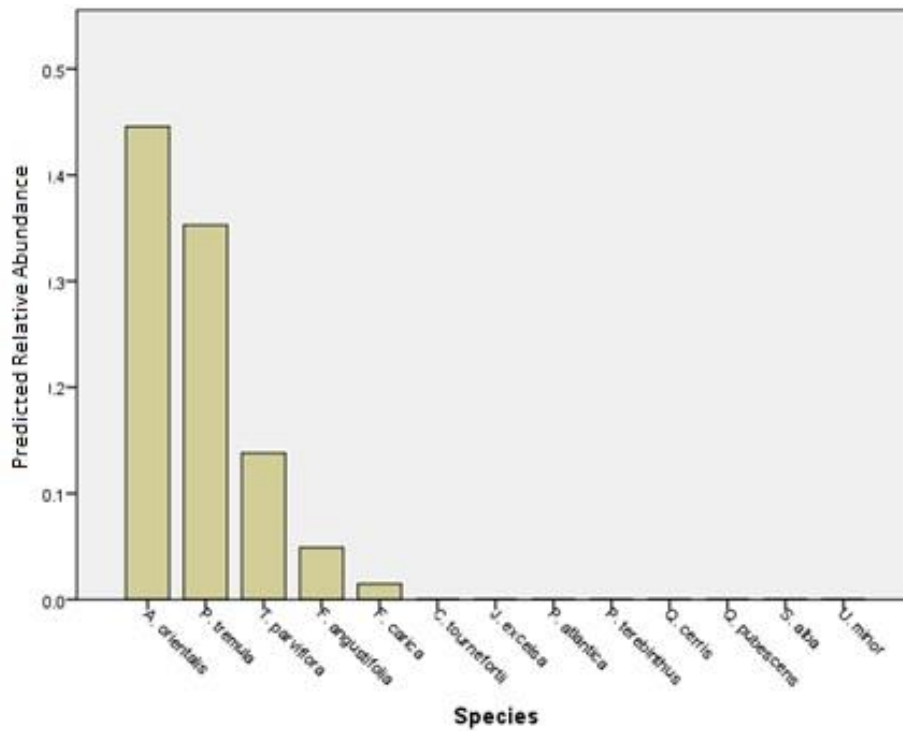


Figure 5: Distribution of modelled tree species, 10km of Boncuklu. Predicted Relative Abundance calculated from the PFN for each species

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351 4.1.3. CM: Distribution of trees within 10km radius of Early Holocene Pınarbaşı

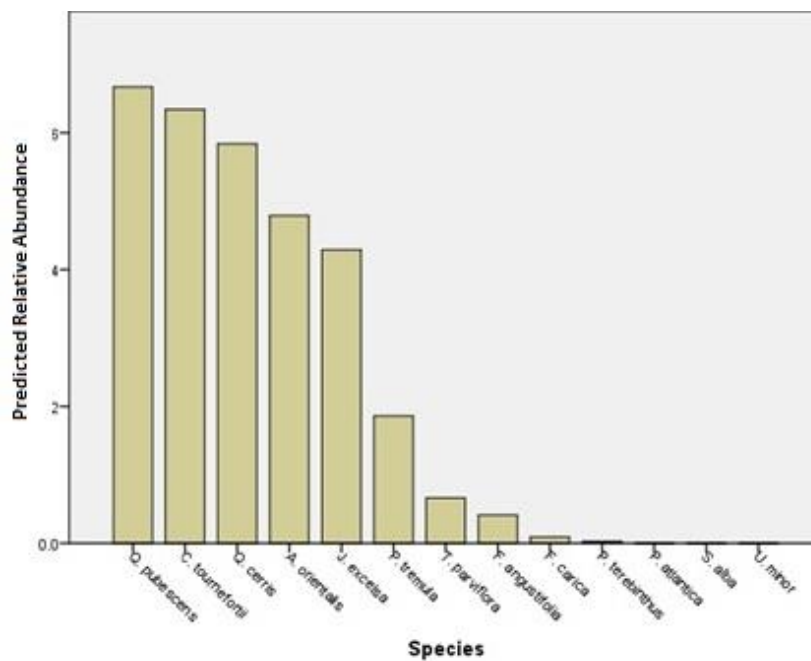
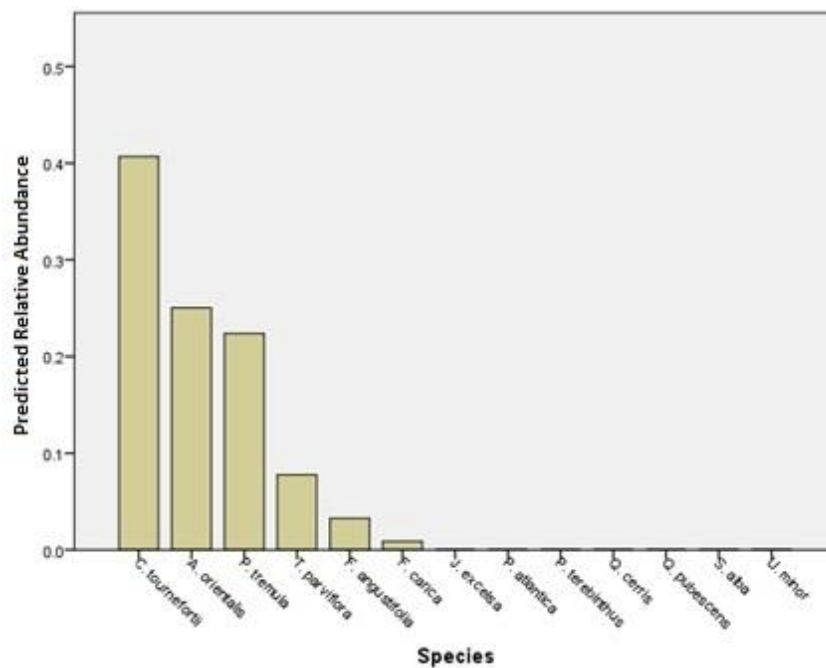


Figure 6: Distribution of modelled tree species, 10km of Pınarbaşı. Predicted Relative Abundance calculated from the PFN for each species



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#### 4.1.4. SCM: Distribution of trees within 10km radius of Early Holocene Çatalhöyük



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Figure 7: Distribution of modelled tree species, 10km Çatalhöyük. Predicted Relative Abundance calculated from the PFN for each species

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356 *Early Holocene Phase Results – Grasses*

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## 4.2.1. Distribution of grass species across the Early Holocene Konya Plain

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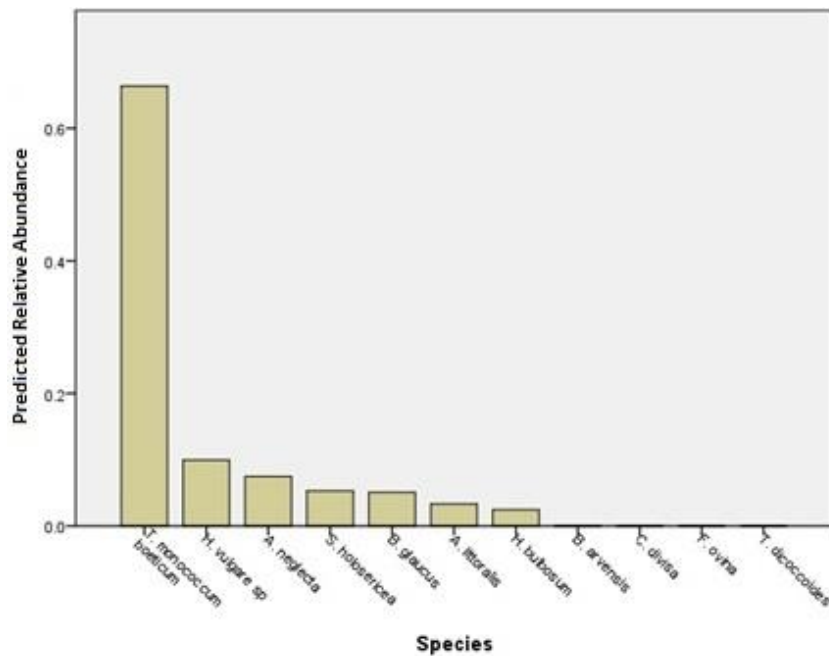


Figure 8: *Distribution of modelled grass species, Konya Plain. Predicted Relative Abundance calculated from the PFN for each species*

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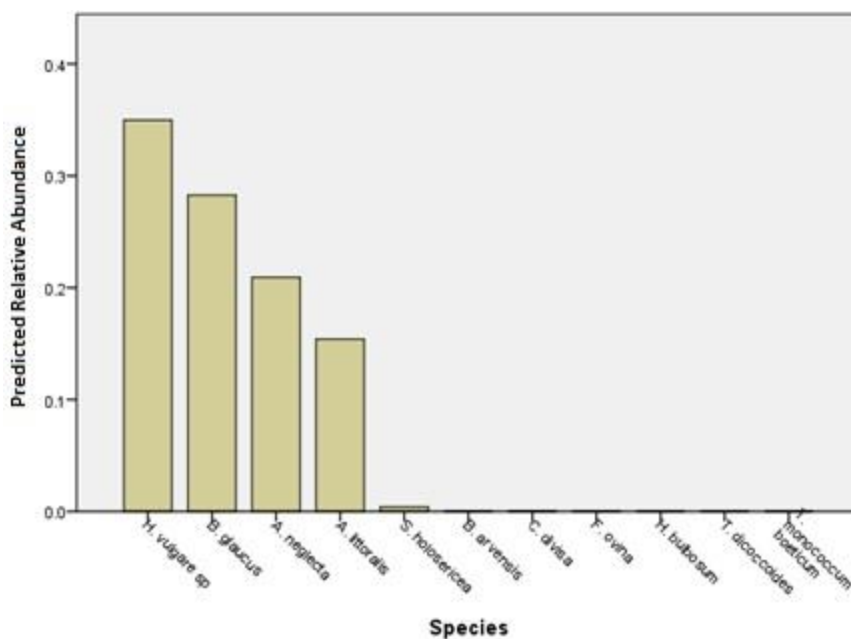
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4.2.2 SCM: Distribution of grasses within 10km radius of Early Holocene Boncuklu



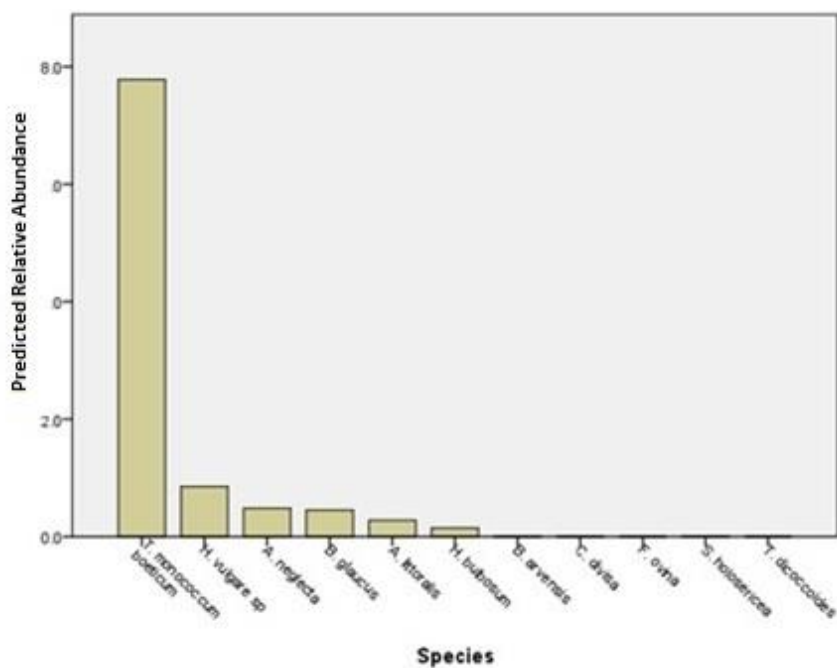
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Figure 9: Distribution of modelled grass species, 10 km Boncuklu. Predicted Relative Abundance calculated from the PFN for each species

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## 401 4.2.2. SCM: Distribution of grasses within 10km radius of Early Holocene Pınarbaşı

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Figure 10: Distribution of modelled grass species, 10km Pınarbaşı.  
 Predicted Relative Abundance calculated from the PFN for each species

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## 4.2.3. SCM: Distribution of grasses within 10km of Early Holocene Çatalhöyük

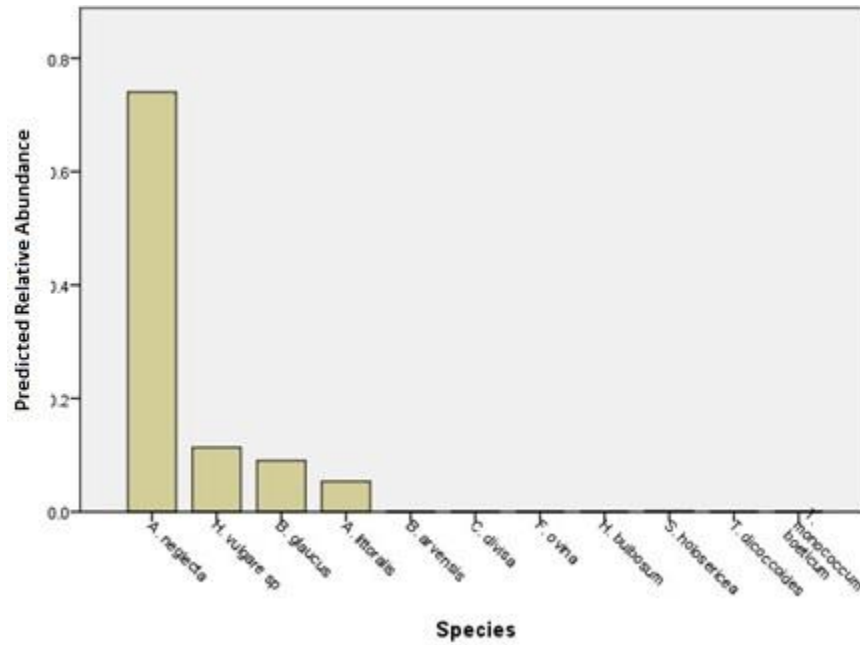


Figure 11: Distribution of modelled grass species, 10km Early Holocene Çatalhöyük. Predicted Relative Abundance calculated from the PFN for each species

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## 434 4.5 Summed PFN Site Catchment Models (SCMs)

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436 4.5.1. Summed PFN SCMs – Early Holocene trees (10 km catchment area of  
437 Pınarbaşı, Boncuklu and Çatalhöyük, and the Konya plain)

438

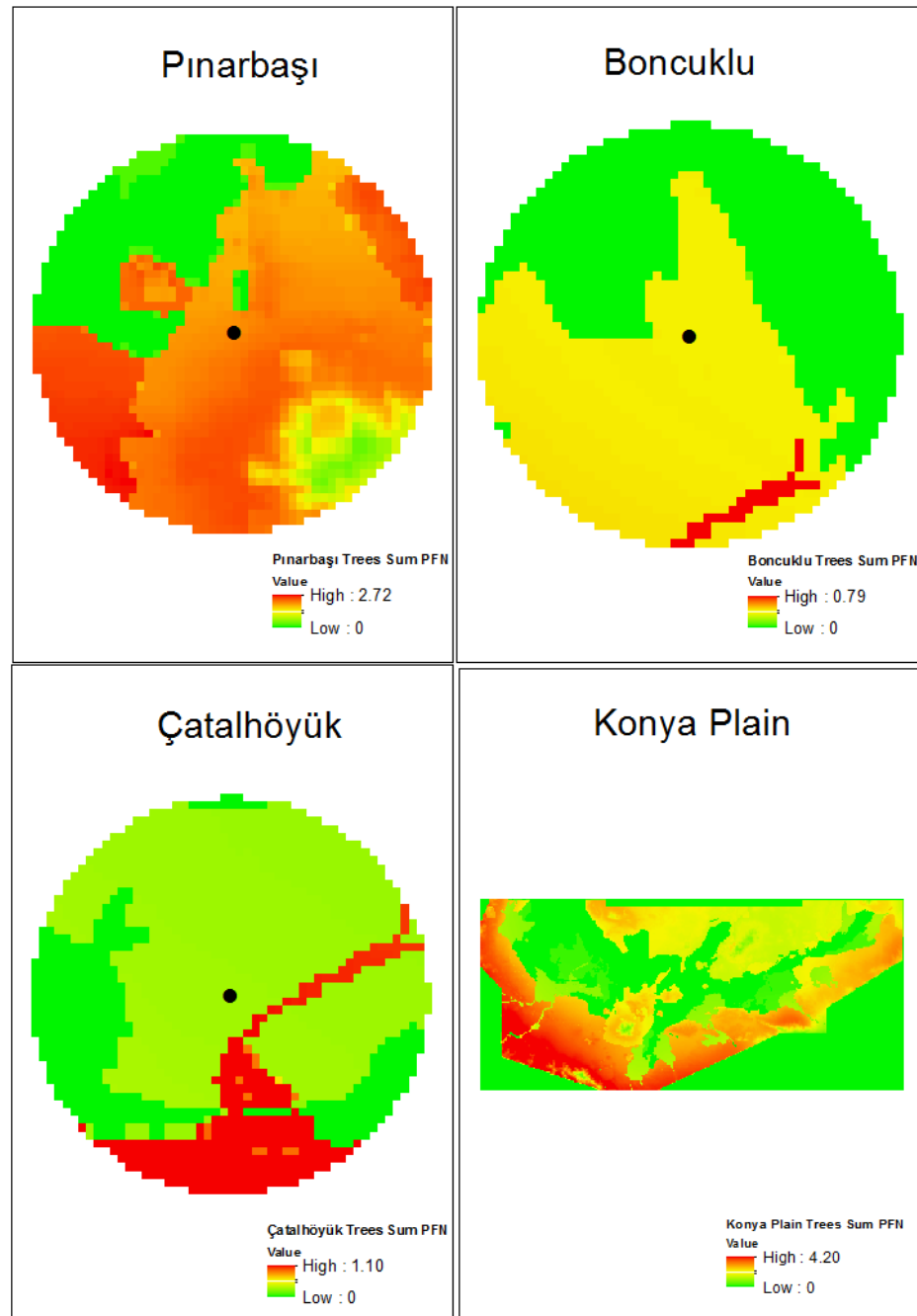


Figure 12: Summed PFN SCMs trees, 10km radius of each site, and summed PFN for the entire Konya Plain

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4.5.2. Summed PFN SCMs – Early Holocene grasses (10 km catchment area of Pınarbaşı, Boncuklu and Çatalhöyük, and the Konya plain)

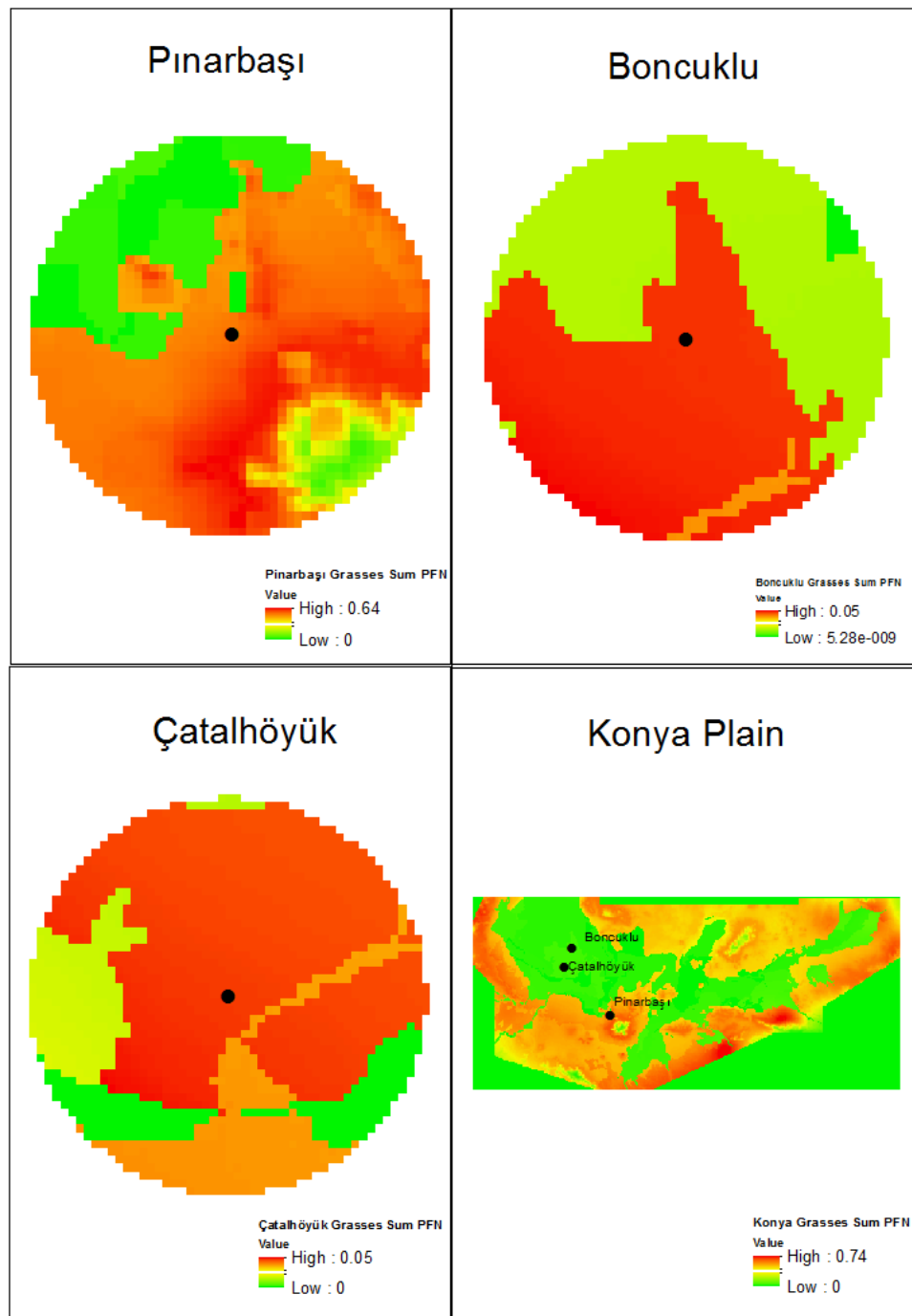
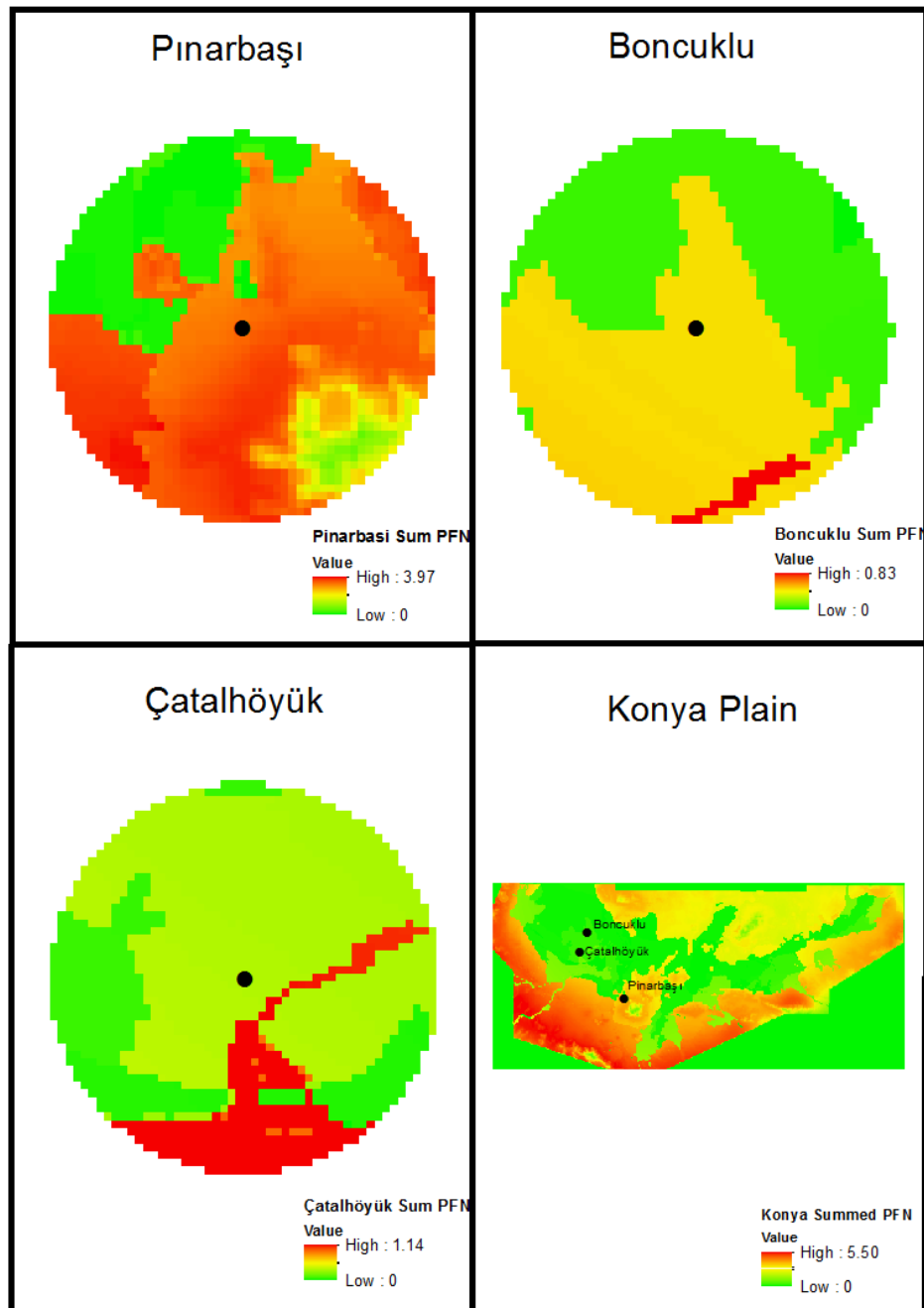


Figure 13: Summed PFN SCMs, grasses, 10km radius of each site and for the entire Konya Plain

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4.5.3. Total Summed PFN SCMs (10 km catchment area of Pınarbaşı, Boncuklu and Çatalhöyük, and the Konya plain)



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445 *Figure 14: Summed PFN SCMs all plant species, 10km radius of each site and for the entire*  
 446 *Konya Plain*

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## 452 4.6 Cost Surfaces

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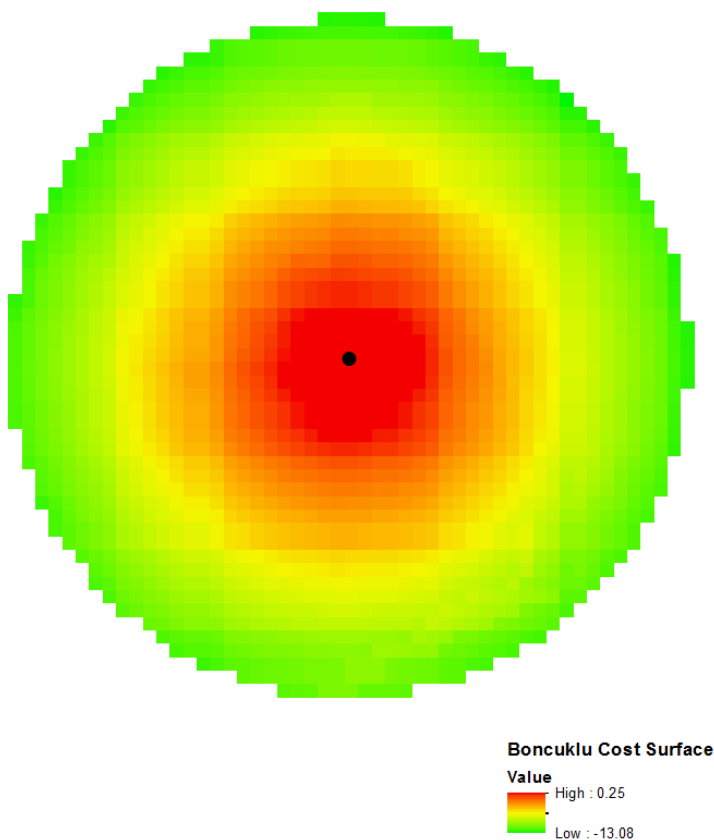
454 *Boncuklu*

Figure 15: Cost surface Boncuklu

455 The discounted PFN surface for Boncuklu appears identical to a distance layer. This is due to  
 456 the uniformity of the terrain and the species found within 10km of Boncuklu. Theoretically,  
 457 there appears to be no particular benefit to foraging in any specific direction away from the  
 458 site. The theoretical implication is that the prehistoric inhabitants of Boncuklu might have  
 459 selected site location for uniformly exploiting all the surrounding territory.

460

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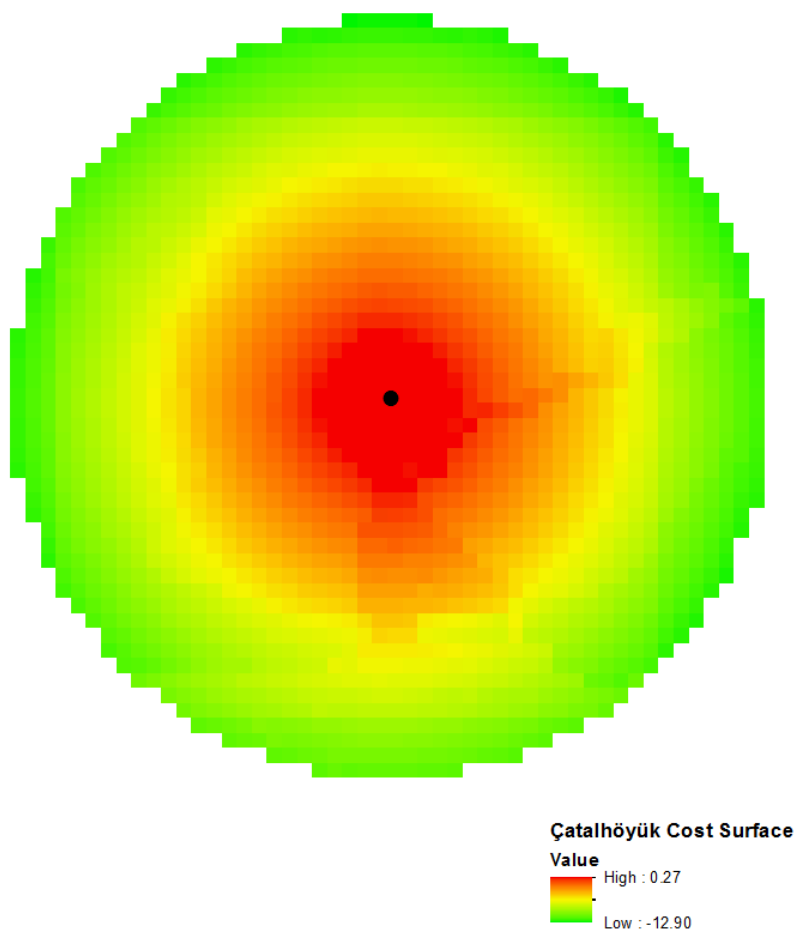
462 *Çatalhöyük*

463 The Çatalhöyük discounted PFN surface, like that of Boncuklu, is remarkably uniform,  
 464 deviating very little from the simple distance from site surface. Again, it seems as if its  
 465 inhabitants selected the site location in order to be centrally placed for non-agricultural  
 466 resource procurement. However, given that (in contrast to Boncuklu and Pınarbaşı) the  
 467 Çatalhöyük economy was predicated on mixed agropastoral production, the main criterion for

468 site location almost certainly was the availability of land suitable for fixed-plot intensive  
 469 horticulture in the immediate vicinity of the site that was least prone to the risk of annual  
 470 flooding (Charles et al., 2014).

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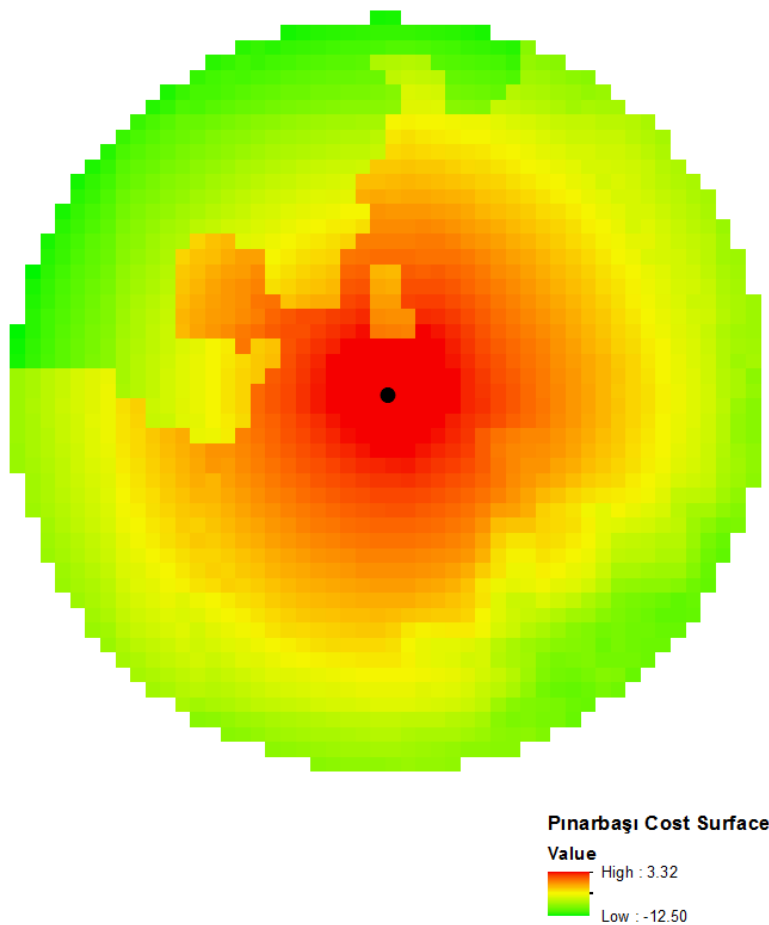


*Figure 16: Çatalhöyük cost surface*

473

474 *Pınarbaşı*

475 Like Boncuklu and Çatalhöyük, Pınarbaşı is centrally located within an area of resource  
 476 diversity. However, the cost-benefit surface is substantially less uniform than for these later  
 477 sites. This is due to the location of Pınarbaşı on the edge of the plain, on the foothills of  
 478 Karadağ. The more complex relief in this area introduces greater variation in the PFN.



479

480 *Figure 1713: Pınarbaşı cost surface*

481

482 **5. Discussion**

483 Understanding resource choice by prehistoric communities in the early Holocene is of  
 484 clear interest to archaeologists reconstructing the transition from foraging to farming, and  
 485 economic decision-making during this critical period. The degree to which resource use  
 486 inferred from archaeological assemblages corresponds to the predicted resource availability  
 487 and distribution in the same geographical area and site territories can thus provide useful  
 488 insights concerning the relative contribution of environmental availability and human agency  
 489 in shaping prehistoric landscapes.

490 According to the SDM predictions described in the previous sections, the most common  
 491 tree taxa found within 10km of early Holocene Pınarbaşı were *Quercus*, *Celtis*, *Amygdalus*  
 492 and *Juniperus*. Asouti (2003) observed that *Amygdalus*, followed in much lower frequencies  
 493 by *Celtis* and *Pistacia*, dominated the anthracological assemblage of late Neolithic (7<sup>th</sup>  
 494 millennium cal BC) Site B of Pınarbaşı, a pattern also verified by the work of Kabukcu on the

495 9<sup>th</sup> millennium cal BC assemblage from Site A (Kabukcu, 2017a). Fairbairn et al. (2014)  
496 observed that almond (*Amygdalus*), terebinth (*Pistacia*) and hackberries (*Celtis*) dominate the  
497 non-wood archaeobotanical assemblage. By contrast, *Quercus* and *Juniperus* had a minimal  
498 presence in the anthracological remains, and they were not present at all in the non-wood  
499 archaeobotanical assemblage. This pattern is overall consistent with SDM predictions, with  
500 *Amygdalus* and *Celtis* being among the taxa predicted to have the greatest presence during the  
501 early-late Holocene around Pınarbaşı. *Amygdalus* seems to have been the preferred fuel wood  
502 and nut food source at Pınarbaşı throughout the prehistoric period.

503 The early Holocene 10km radius of Boncuklu is predicted by the SDM as a landscape  
504 dominated by woodland taxa such as *Amygdalus*, *Populus*, *Tamarix* and *Fraxinus*. Asouti and  
505 Kabukcu (2014) and Kabukcu (2017a; forthcoming.) report the high presence of Salicaceae  
506 (*Populus/Salix*) in the Boncuklu anthracological assemblage. *Amygdalus*, *Pistacia*, *Fraxinus*,  
507 *Celtis*, *Juniperus* and *Quercus* appear in low frequencies but are relatively ubiquitous in the  
508 anthracological remains (Kabukcu, 2017a; forthcoming).

509 The non-wood archaeobotanical assemblage (Baird et al., 2012) has also indicated  
510 the presence of *Amygdalus*, *Pistacia* and *Celtis*. The partial disparities observed between the  
511 predicted SDM distributions of arboreal taxa and their presence and frequencies in the  
512 combined archaeobotanical and anthracological assemblages may be partly explained as the  
513 result of the existence of extensive marsh and wetland areas around Boncuklu during the  
514 prehistoric periods, something which could not be computed with the degree of spatial  
515 precision required by the SDM model that was by necessity reliant on modern soil type  
516 distributions. It is also likely that species such as *Quercus* and *Juniperus* were harvested and  
517 brought to the site from distant habitats in the surrounding upland zone, when their ecological  
518 preferences are taken into consideration (Asouti and Kabukcu, 2014). Taxa such as  
519 *Amygdalus*, *Pistacia* and the less abundant (in the anthracological assemblage) riparian  
520 *Fraxinus* and *Ulmus* may have had more restricted distributions in the Boncuklu 10km radius,  
521 because of the prevalence of marsh and submerged wetland habitats in the immediate vicinity  
522 of the site.

523 At Çatalhöyük the dominant tree species predicted by the SDM during the Holocene  
524 are *Celtis*, *Amygdalus*, *Populus*, *Tamarix* and *Fraxinus*. *Celtis* and Salicaceae (*Populus/Salix*)  
525 are among the most ubiquitous charcoal taxa identified at Çatalhöyük, although they are  
526 usually (if not always) present in relatively low frequencies throughout the long

527 anthracological sequence sampled from the Neolithic East mound spanning ~1000 years (cf.  
528 Asouti and Hather 2001; Asouti 2005, 2013; Asouti and Kabukcu 2014; Kabukcu, 2017a, b).  
529 However, other taxa that are ubiquitous and abundant in the anthracological assemblage such  
530 as *Quercus*, *Juniperus* and *Ulmus*, are not projected by the SDM to have been abundant in the  
531 environs of the site. Conversely, taxa that are projected by the SDM to have been abundant  
532 near the site (*Tamarix*, *Fraxinus*) have registered low frequencies in the anthracological  
533 assemblage. On this basis, the SDM appears to confirm the proposition that *Quercus* and  
534 *Juniperus* were preferentially selected as firewood and timber that were harvested in more  
535 distant localities to the south of the site (Asouti and Kabukcu, 2014). Furthermore, the  
536 disparity observed in the representation of specific components of the riparian vegetation  
537 (*Ulmus*, *Fraxinus*, *Tamarix*) between the SDM and the anthracological dataset is likely to  
538 pinpoint significant differences between the prehistoric and modern/historical distribution  
539 and ecology of riparian and wetland habitats around Çatalhöyük. Similar to the situation  
540 observed at Boncuklu, the early Holocene presence of now-extinct wetland and riparian  
541 micro-ecologies in the environs of Çatalhöyük is likely to be the principal reason why  
542 riparian taxa appear to be somewhat misrepresented in the maximum and mean pixel values  
543 graphs. However, it should be noted here that the Individual Species Surfaces produced by  
544 the SDM model discriminated very effectively between classic riparian arboreal taxa (e.g.,  
545 *Fraxinus*, *Ulmus*) and those that can be ubiquitous in more typical wetland/marsh habitats as  
546 well (i.e., *Tamarix*, *Salix/Populus*) (see Supplementary data pp. 9-13). Salicaceae are also  
547 ubiquitous and abundant in the anthracological assemblage from Boncuklu, a site predicted to  
548 have occupied more typical wetland settings, while *Ulmus* and *Fraxinus* are better  
549 represented at Çatalhöyük that was situated in comparatively better drained alluvial settings.

550         The projected distribution of grassland taxa in the Konya plain is dominated by  
551 *Triticum monococcum* ssp. *boeoticum* (einkorn) followed by *Hordeum vulgare* ssp.  
552 *spontaneum* (barley). The SDM-predicted wide distribution of both taxa in early Holocene  
553 south-central Anatolia (and the corresponding predicted absence of the emmer wheat  
554 progenitor *Triticum turgidum* ssp. *dicocoides*) thus provide strong independent verification  
555 of previous floristic surveys as summarized by Zohary et al. (2012). However, while  
556 Fairbairn et al. (2014) noted the presence of both einkorn and barley in the archaeobotanical  
557 assemblages from the 9<sup>th</sup> millennium cal BC Site A at Pınarbaşı, this was limited to single  
558 grain finds that were intrusive from later levels. Einkorn and barley progenitors are also  
559 absent from the Boncuklu macrobotanical assemblage. The discrepancy between the SDM-

560 predicted distribution of these taxa and their absence from the archaeobotanical assemblages  
561 appears therefore to be highly significant. The implication is that the wider Konya plain  
562 region was ecologically suitable for both wild einkorn and barley during the Holocene, yet  
563 neither taxon appears to have been targeted as a plant food resource by prehistoric  
564 communities. Moreover, their absence from the archaeobotanical assemblages cannot be  
565 attributed to inadequate sampling or preservation and retrieval biases; both sites have been  
566 intensively sampled for macrobotanical remains (Baird, 2012; Baird et al., 2012; Fairbairn et  
567 al., 2014). The SDM results therefore appear to confirm that 9<sup>th</sup> millennium cal BC hunter-  
568 gatherer and cultivator-forager communities in the Konya plain were intentionally not  
569 harvesting and/or managing otherwise locally available cereal crop progenitor taxa. Other  
570 grass taxa that are predicted by SDM to have been relatively abundant in the landscape  
571 include *Aegilops* and *Bolboschoenus*. *Bolboschoenus glaucus* seeds have been identified at  
572 Pınarbaşı although *Aegilops* was absent (Fairbairn et al., 2014). At Boncuklu, *Bolboschoenus*  
573 was common, alongside reeds (*Phragmites*) and other wetland and steppe grass taxa. The  
574 presence of wetland and steppe grass taxa accords well with the locations of Pınarbaşı and  
575 Boncuklu in direct proximity to extensive wetland areas and steppe-wetland ecotones. While  
576 one should not altogether exclude the possibility that these taxa formed part of the  
577 subsistence repertoire at both sites, at the same time it is also possible that they may  
578 represent, to varying degrees, environmental “noise” in the archaeobotanical assemblages.  
579 The extensive use of reeds (*Phragmites*) as building, fuel and craft materials is also verified  
580 at both sites (Baird, 2012; Baird et al., 2012; Kabukcu, forthcoming). Although domesticated  
581 cereal crops have been attested at Boncuklu (Baird et al., 2012) very likely representing  
582 introductions from other regions, their low frequencies in the archaeobotanical assemblage  
583 suggest that they played a minor role in the diet of the inhabitants of the site. This is also  
584 confirmed by the study of human remains indicating the absence of dental carries at  
585 Boncuklu, which point to the minimal consumption of cereal grain by the site inhabitants  
586 (Pearson, forthcoming).

587         The apparent avoidance of cereal crop progenitor taxa as subsistence resources by the  
588 inhabitants of 9<sup>th</sup> millennium cal BC Pınarbaşı and Boncuklu, despite the SDM-predicted  
589 wide availability of wild-type einkorn and barley in the local landscape, is not a phenomenon  
590 that is unique to south-central Anatolia. Comparable patterns of plant-derived subsistence  
591 practices are evidenced from several early Holocene habitation sites in eastern Anatolia, all of  
592 which are firmly located within the expected geographical ranges of crop progenitor species.

593 Virtually no wheat or barley remains have been identified in Hasankeyf höyük, dated to the  
594 second half of the 10<sup>th</sup> millennium cal BC; the Hasankeyf non-wood botanical assemblage is  
595 dominated by *Amygdalus*, *Pistacia* and *Celtis* alongside as yet indeterminate nut remains  
596 (Miyake et al., 2012; Tanno et al., 2016). Other sites in eastern Anatolia and northwest  
597 Zagros (e.g., Hallan Çemi, Demirköy, Qermez Dere, M'lefaat) and in the southern Levant  
598 (e.g., 'Iraq ed-Dubb, Netiv Hagdud) are also reported to contain large quantities of non-cereal  
599 seed taxa and nuts (Colledge, 2001; Savard et al., 2006; Willcox and Savard, 2011; Willcox,  
600 2012). Another eastern Anatolian site, Körtik Tepe, has provided evidence for the harvesting  
601 of large to medium-seeded grasses, although (significantly) progenitor taxa formed a very  
602 small component of its archaeobotanical assemblage (Riehl et al., 2012) while comparable  
603 results regarding the relative under-representation of cereal crop progenitors compared to  
604 other wild grass taxa have also emerged from the long sequence sampled at the aceramic site  
605 of Chogha Golan in the central Zagros (Waide et al. 2018). Overall, this pattern suggests the  
606 existence of strong cultural preferences, likely determined by small-scale fluctuations in local  
607 microecologies alongside culturally mediated traditions of subsistence resource management  
608 strategies, which operated quite independently of plant resource availability in proximate and  
609 more distant site territories (Asouti 2017).

610

## 611 **6. Conclusion**

612 The application of the SDM method presented in this paper provides a powerful tool for the  
613 formal reconstruction of plant resource availability with a much higher degree of  
614 geographical and spatial precision when compared to traditional biogeographic  
615 reconstructions (e.g., Zohary, 1973) that have been widely applied to Southwest Asia (e.g.,  
616 Zohary, 1973). SDM also provides a useful means for evaluating the degree of convergence  
617 and overlap between environmental availability and cultural choice filters affecting the  
618 composition of archaeobotanical assemblages. This is due to the unique capacity of SDM to  
619 generate independent palaeoenvironmental datasets that can be then directly compared to  
620 archaeological assemblages. Other distinctive advantages offered by SDM include its ease of  
621 application and thus its transferability to any world region, due to its reliance on open source  
622 data. The results produced by the application of SDM in the Konya plain of south-central  
623 Anatolia will be further refined and tested against the results of ongoing palaeoenvironmental  
624 analyses that are currently being prepared by the project team for publication.

625

626

627

628 **7. Acknowledgements**

629 This research was funded by the Leverhulme Trust Standard Research Grant no. RPG 2012-  
 630 476 (Project title: “Unfamiliar landscapes: the transition from hunting-gathering to  
 631 agriculture in the high-altitude plateau wetlands of Central Anatolia, Turkey”). We are  
 632 grateful to Douglas Baird, Jessica Pearson, Louise Martin, and Andrew Fairbairn for useful  
 633 discussions and advice. We are grateful also to Erich Fisher, and another anonymous  
 634 reviewer for their helpful comments and suggestions on the earlier manuscript.

635

636

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