**Supplementary information – Online Resource 1**

**Title**: Changes in climate drove vegetation and land use dynamics at the onset of farming in Europe

**Authors**: Lieveke van Vugta,b, Erika Gobeta,b, César Morales-Molinoa,b,c, Kathrin Ganza,b, Tryfon Giagkoulisd, Antonietta Knetgea,e, André F. Lottera,b, Hendrik Vogelb,f, Martin Grosjeanb,g, Amy Bogaardh, Kostas Kotsakisd, Albert Hafnerb,i, Willy Tinnera,b

1. Institute of Plant Sciences, University of Bern, Altenbergrain 21, 3013 Bern, Switzerland
2. Oeschger Centre for Climate Change Research, University of Bern, Hochschulstrasse 4, 3012 Bern, Switzerland
3. Grupo de Ecología y Restauración Forestal (FORECO), Departamento de Ciencias de la Vida, Facultad de Ciencias, Universidad de Alcalá, 28805, Alcalá de Henares, Spain
4. Department of Archaeology, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece
5. Botany Department, Trinity College Dublin, Dublin 2, Ireland
6. Institute of Geological Sciences, University of Bern, Baltzerstrasse 1+3, 3012 Bern, Switzerland
7. Institute of Geography, University of Bern, Hallerstrasse 12, 3012 Bern, Switzerland
8. School of Archaeology, University of Oxford, 1 South Parks Road, Oxford OX1 3TG, United Kingdom
9. Institute of Archaeological Sciences, University of Bern, Mittelstrasse 43, 3012 Bern, Switzerland

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Supplementary table S1: Overview of the radiocarbon dates from the master core of the Limni Zazari sediment record. | | | | | | |
| Depth (cm) | Lab. code | Material | 14C-Age  (yr BP) | Calibrated age  (cal yr BP, 2σ-range) | Median age (cal yr BP) | Modelled age in diagrams (cal yr BP) |
| 108-1101 | BE-6440.1.1 | Bud, seed, leaf fragments | 725 ± 40 | 565-727 | 669 | 717 |
| 132-136 | BE-15764.1.1 | Bud scales, leaf fragments, *Carex* seed + fruit | 1345±40 | 1176-1342 | 1269 | rejected |
| 152-154 | BE-15763.1.1 | Leaf fragments | 505±70 | 331-652 | 532 | rejected |
| 167-169 | BE-15762.1.1 | (Charred) leaf fragments | 1255±90 | 971-1306 | 1169 | 1212 |
| 191-195 | BE-15761.1.1 | *Pinus* anther, (charred) leaf fragments, bud scales | 1785±70 | 1532-1867 | 1672 | 1922 |
| 210-2121 | BE-6725.1.1 | Leaf fragments | 2,770 ± 20 | 2784-2933 | 2861 | 2845 |
| 223-225 | BE-15760.1.1 | Leaf fragments | 2910±75 | 2854-3327 | 3058 | 3189 |
| 233-235 | BE-15759.1.1 | Leaf fragments, charcoal | 3505±40 | 3648-3881 | 3772 | 3748 |
| 246-250 | BE-15758.1.1 | (Charred) leaf fragments, bud scales | 4070±140 | 4149-4956 | 4574 | 4293 |
| 277-2791 | BE-6439.1.1 | *Betula* seed, leaf fragments, 2 bud scales | 4,495 ± 40 | 4980-5306 | 5159 | 5151 |
| 309-3111 | BE-6438.1.1 | *Pinus* seed, 1/2 seed, leaf fragment | 5,405 ± 20 | 6126-6284 | 6238 | 6078 |
| 338-339 | BE-16306.1.1 | Leaf fragments, bud scale | 5565±35 | 6294-6403 | 6349 | 6390 |
| 366-370 | BE-16307.1.1 | (Charred) leaf fragments, seed wing, anther | 6210±90 | 6884-7319 | 7098 | 7048 |
| 376-3781 | BE-6724.1.1 | Twig, epidermis, leaf fragments | 6,305 ± 20 | 7165-7268 | 7206 | 7227 |
| 388-389 | BE-16308.1.1 | Bud scale, bark, charred grass, terrestrial plant indet. | 6830±60 | 7575-7785 | 7660 | 7618 |
| 400-4021 | BE-6979.1.1 | Charcoal | 6,920 ± 120 | 7571-7972 | 7763 | 7891 |
| 406-4101 | BE-6978.1.1 | Leaf fragments, bud scale | 7,370 ± 150 | 7871-8450 | 8183 | 8098 |
| 429-432 | BE-16309.1.1 | (Charred) leaf fragments, grass cf. | 7735±100 | 8347-8975 | 8525 | 8769 |
| 439-4411 | BE-6980.1.1 | Leaf fragment | 8,300 ± 130 | 9009-9531 | 9275 | 9156 |
| 461-463 | BE-16310.1.1 | Charred leaf fragments, bud scale, (charred) bark, seed wing | 8720±65 | 9540-10107 | 9691 | 9917 |
| 467-4711 | BE-6977.1.1 | Leaf fragments, charcoal | 7,730 ± 50 | 8415-8595 | 8502 | rejected |
| 472-4761 | BE-6437.1.1 | Asteraceae seed, bud, leaf fragments | 9,560 ± 50 | 10702-11140 | 10923 | 10826 |
| 505-5151 | BE-6976.1.1 | Bud scale, charcoal | 3,830 ± 90 | 3977-4514 | 4234 | rejected |
| 560-5651 | BE-6346.1.1 | Twigs, bud | 15,830 ± 40 | 18951-19200 | 19084 | 19089 |

1 Previously published by Gassner et al. (2020).

A graph of a graph

Description automatically generated with medium confidence

**Supplementary figure S1:** Age-depth model and lithology for the complete Limni Zazari sediment record. The blue and red horizontal integrals show the probability density functions of the individual radiocarbon dates (IntCal 20; Reimer et al. 2020), the red dotted line represents the modelled chronology (Bacon; Blaauw and Christen 2011), the grey envelop shows the 95% confidence interval, and the black dashed lines show the 95% confidence intervals from the generalised additive model (GAM; Heegaard et al. 2005). The red radiocarbon dates were treated as outliers and rejected from the age-depth model.

**Supplementary figure S2**: Principal component analysis. PCA scatterplot of the samples (bottom) and selected taxa (top). Microscopic charcoal influx (Char) as a proxy for fire, *Sporormiella* type influx (Spor) as a proxy for grazing, July and January insolation (July, Jan; Laskar et al., 2004), and the natural logarithmic transformed ratio of calcium and titanium counts (ln(Ca/Ti)) as a proxy for hydrological conditions (higher values indicate wetter conditions) are supplementary explanatory variables and were projected passively onto the ordination (red arrows). Axis 1 explains 38% of the variance in the pollen assemblages and likely represents a gradient from more open deciduous oak dominated vegetation, to more closed pine-deciduous oak forests. Axis 2 explains 16% of the variance and is related to climatic and anthropogenic disturbance. Samples are grouped according to the local pollen assemblage zones (LPAZ).

A screenshot of a graph

Description automatically generated

**Supplementary figure S3**: Cross-correlation diagrams from Limni Zazari with: a. Microscopic charcoal influx (# cm-2 yr-1) as a proxy for fire activity versus selected pollen percentages (arboreal pollen, *Quercus frainetto* type, *Pinus*, *Artemisia*, *Polygonum* *aviculare* type, *Plantago lanceolata* type, Cerealia type) and the land use probability index (LUP) for zones ZAZ-3 to ZAZ-6 (8700–7130 cal yr BP), 1 lag corresponds to 27.3±5.7 years;   
b. -ln(Ca/Ti) as a proxy for moisture availability versus selected pollen percentages and the LUP for zones ZAZ-6 to ZAZ-8 (7720–6310 cal yr BP), 1 lag corresponds to 22.9±7.2 years. The dotted horizontal lines mark the significance level (p<0.05). The sign of ln(Ca/Ti) was reversed, to emphasise the response of vegetation to a decrease instead of an increase in moisture.

A graph of a graph of a graph

Description automatically generated with medium confidence

**Supplementary figure S4**: Comparison of the summary pollen diagram from Gassner et al. (2020) with XRF measurements. The data has been plotted with the new age-depth model (Fig. S1). Titanium (Ti) counts are used as a proxy for lithogenic input; increased calcite (Ca, ln(Ca/Ti)) content is linked to more humid and/or warmer conditions, with higher values indicating wetter and warmer conditions; the ratio of rubidium and potassium (ln(Rb/K)) is used as a proxy for the chemical alteration of sediments deposited, with higher values indicating less alteration; the ratio of zirconium and aluminium (ln(Zr/Al+1)) is used as an indicator for increased grain size and lake level low stands, with higher values indicating coarser grain-size and lower lake levels. Important climatic and archaeological periods are marked by dotted lines; Bø-Al = Bølling-Allerød., YD = Younger Dryas.

References

Blaauw M, Christen JA (2011) Flexible paleoclimate age-depth models using an autoregressive gamma process. *Bayesian Analysis* 6(3): 457–474.

Gassner S, Gobet E, Schwörer C, van Leeuwen J, Vogel H, Giagkoulis T, Makri S, Grosjean M, Panajiotidis S, Hafner A, Tinner W (2020) 20,000 years of interactions between climate, vegetation and land use in Northern Greece. *Vegetation History and Archaeobotany* 29: 75–90.

Heegaard E, Birks HJ, Telford RJ (2005) Relationships between calibrated ages and depth in stratigraphical sequences: an estimation procedure by mixed-effect regression. *The Holocene* 15(4): 612–618.

Reimer PJ, Austin WEN, Bard E, Bayliss A, Blackwell PG, Bronk Ramsey C, Butzin M, Cheng H, Edwards RL, Friedrich M, Grootes PM, Guilderson TP, Hajdas I, Heaton TJ, Hogg AG, Hughen KA, Kromer B, Manning SW, Muscheler R, Palmer JG, Pearson C, van der Plicht J, Reimer RW, Richards DA, Scott EM, Southon JR, Turney CSM, Wacker L, Adolphi F, Büntgen U, Capano M, Fahrni SM, Fogtmann-Schulz A, Friedrich R, Köhler P, Kudsk S, Miyake F, Olsen J, Reinig F, Sakamoto M, Sookdeo A, Talamo S (2020) The IntCal20 Northern Hemisphere Radiocarbon Age Calibration Curve (0–55 cal kBP). *Radiocarbon* 62(4): 725–757.