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Feeding the Pyramid builders: early agriculture at Giza in Egypt

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Highlights

- Two cores extracted from the Khufu branch of the Nile at Giza
- A 7600-year record of agropastoral activities from the pyramids area
- Insight into the first complex societies at Giza
- The area was mainly a pastoral landscape when the necropolis was built
- The Third Intermediate Period was the worst phase for agropastoral activities

Abstract

While the exact technical processes employed in the construction of the pyramids are still a subject of ongoing debate, it is widely recognized that the Giza Plateau served as a hub where various trades converged with the common objective of building the necropolis. Of particular importance was the development of a local and sustainable food supply for the thousands of laborers involved in this monumental undertaking. Here, we explore the long-term behavioural mechanisms that led human societies to gradually colonize the Nile swamps at Giza. They developed herding and farming, paving the way for greater human exploitation of the area during the Dynastic Egypt. We show that transhumance tribes, originally from the Eastern Sahara, settled along the Giza Plateau 5200 years ago, primarily engaging in herding and, more sporadically, agriculture. Giza was transformed into a pastoral landscape, with the development of large swaths of the floodplain, providing societies with permanent access to livestock produce (e.g. proteins, milk, meat and wool). Our palaeoecological data reveal that the initial complex societies at Giza were deeply rooted in transhumance, pastoralism and animal husbandry. These activities played a fundamental role in establishing the foundations of a robust and sustainable food system, while also serving as a crucial logistical support for the subsequent construction of the monumental structures that celebrated the grandeur of pharaonic Egypt.

Keywords

Giza necropolis, Khufu branch of the Nile, agriculture, livestock breeding, Dynastic Egypt, Palynology

1. Introduction

Dominating the agricultural landscape from the plateau west of the Nile, the Giza pyramids stand as enduring symbols of the might and authority of the kings of the Old Kingdom (4th dynasty; Shaw, 2000), immortalizing their reign over the land of Egypt. The Great Pyramid of Giza, one of the Seven Wonders of the Ancient World, was erected by King Khufu (first regnal year: 2613-2577 BCE; Bronk-Ramsey et al., 2010). The remaining two pyramids were constructed by King Khafre (reigning from approximately 2586-2548 BCE; Bronk-Ramsey et al., 2010), who was the son of Khufu, and by King Menkaure (reigning from approximately 2564-2524 BCE; Bronk-Ramsey et al., 2010), who was the grandson of Khufu. The pyramids are included in a wider complex that comprises queens' pyramids, burials of real and/or symbolic boats, mastaba tombs (for family members and nobility), and temples linked by causeways. Scholars have estimated that the construction of the Great Pyramid was finalized within approximately 20-23 years (Strouhal, 1992; Edwards, 2003), employing a diverse workforce that included stonemasons, metalworkers, carpenters, foremen, and countless other workers. The collective size of this eclectic labour force exceeded 10,000 individuals (Edwards, 2003). Associated with Menkaure's pyramid, a workmen town (the Lost City of the Pyramids - Heit el-Ghurab) has also been unearthed (Lehner and Wetterstrom, 2007; Lehner, 2009; Lehner and Tavares, 2010; Butzer et al., 2013), attesting to the extensive occupation of the area. The notable and recurring influxes of workers to Giza undoubtedly created a substantial demand for food resources, which necessitated the development of a robust logistics system. This system relied on either local production or regional supply, allowing societies to meet the food requirements of the growing population.

Giza was originally located on the now defunct Khufu branch of the Nile (Sheisha et al., 2022) and its seasonal flooding rendered the fertile land attractive for human occupation and shaped its environmental evolution. While little information on agriculture is available for Giza, in Egypt, agriculture was practiced as early as 5200 BCE in the Fayum, then by a succession of Predynastic cultures, facilitating prosperity and social complexity. The Nile valley was a source of agricultural wealth and hosted the cultivation of a wide variety of cereals (wheat, barley, beans, lentils; Garnsey, 1988; Janick, 2002; Tallet, 2015), fruits (date palm, sorghum, grapes; Janick, 2005) and fibrous plants (flax, papyrus; Janick, 2005). Herding (cattle, sheep, goats, poultry; Schafberg and Swalve, 2015; El Mahdy et al., 2016) is often associated with agriculture, as attested by the numerous paintings in the burial chambers. At Giza, our knowledge is based on scant data. The available archaeobotanical data regarding the agricultural resources and cultivation history of Giza derive from information

extracted from mud bricks taken in the eastern cemetery of Khufu's pyramid and in the temple of Menkaure's pyramid (Ayyad et al., 1991) and other sources from different archaeological artifacts (e.g., walls, floors, layers, hearth/fireplaces, foundations) taken at Khentkawes town, a pyramid/priest's town that lies east of Menkaure's pyramid (Malleon, 2016). Ayyad et al. (1991) found that chopped straw from cereal crops dominated the Giza samples and that most of the remaining pollen assemblage comprised weeds associated with local agriculture, not transported by wind or water. Our understanding of food practices at a broader spatial scale relies on the analysis of archaeobotanical studies conducted at various sites. These include Merimde (Krzyszaniak, 1977; Stemler, 1980), Maadi (Caneva et al., 1987; van Zeist and de Roller, 1993), Kom el-Hisn (Moens and Wetterstrom, 1988), Sa El Hagar (Zhao et al., 2020), Kom El Khilgan (Zhao et al., 2021), the KV 63 site in Luxor (Hamdy and Fahmy, 2015), the HK11C locality in Hierakonpolis (Attia et al., 2018), and Helwan cemetery in the Memphis area (Moustafa et al., 2018). Additionally, various written sources have contributed to our knowledge in this field (Ikram, 1995; Perters-Destéract, 2005; Tallet, 2015). No other palaeobotanical synthesis documents the full range of herding and farming activities at the feet of the Giza necropolis.

Here we report a continuous 7600-year record of agropastoral activities spanning from the Predynastic period to the Islamic era (from 7980±80 BCE to 375±80 CE). The cores were extracted from the now defunct Khufu branch of the Nile (Fig. 1) that originally flowed at the base of the Giza necropolis (Sheisha et al., 2022). In a first study, Sheisha et al. (2022) performed a reconstruction of fluvial variations on the Giza floodplain during the last 8,000 years (from the same composite core K-1; Fig. 1). The results showed that the optimal water level of Khufu branch after the local termination of the African Humid Period, estimated at 3550±80 BCE, facilitated the construction of the Giza pyramids during the Fourth Dynasty (Old Kingdom 2686-2160 BCE; Sheisha et al., 2022). The study additionally indicated instances of a diminished annual flood at Giza, occurring at various points in its history. These periods of reduced flood levels were identified as follows: 2225±80 BCE (during the First Intermediate Period), approximately between 1349 and 1338 BCE (after the reign of King Tutankhamun), and from 1275±80 to 375±80 BCE (encompassing the Third Intermediate Period).

In this study, palaeoecological indicators delve into the extensive historical record of herding and farming practices, which constitute a significant cultural heritage of the diverse Egyptian communities residing on the Giza Plateau since the earliest stages of civilization. Non-Pollen

Palynomorphs (NPP) were added to the primary and secondary anthropogenic indicators to further underline human activities in the area. The analytical process differs substantially from the previous study (Sheisha et al., 2022) because we specifically focus on cultural landscapes and limit our hydrological analysis to determining the optimal thresholds for human activities in the face of environmental stresses, including droughts and floods. Our reconstructions show how the rise of agriculture and livestock breeding on the Giza Plateau meshes with the migration of populations from Eastern Sahara to the Nile and how the evolution of these resources followed the emergence and development of ancient Egyptian dynasties.

2. Material and methods

2.1. Cores and chronology

To investigate the evolution of human behaviour at Giza, bio-indicators (pollen grains and non-pollen palynomorphs - NPPs) were extracted from two cores drilled in the Khufu branch of the Nile, termed Giza 1 (890 cm depth; 29°59'04" N, 31°09'07" E; 18 m above sea level) and Giza 4 (700 cm depth; 29°58'40" N, 31°09'39" E; 19 m above sea level; Fig. 1 and Fig. 2). Five radiocarbon dates and pottery sherds were taken from the cores to determine their age (the associated dating error is averaged to ± 80 years for the whole sequence; Fig. 2). All dates are expressed as Before Present (BP), Before Common Era (BCE) and Common Era (CE). The age-depth model was constructed using Clam modelling (version 2.2; Blaauw, 2010). Comparison with previous studies at Giza (Sowada et al., 2020) and Saqqara (Hamdan et al., 2014), as well as the presence of potsherds in the sedimentary deposits, allowed the lower part of the cores to be dated to the Predynastic and Early Dynastic-Old Kingdom periods.

To merge the Giza 1 and 4 cores into a K-1 composite core, stratigraphic and chronological correlations were performed (Fig. 2). The two cores (Giza 1 and Giza 4) are largely homogeneous in the lower part (grey clayey silts; Fig. 2a). Two particular facies (grey silts and sands - grey medium sands) are recorded in cores Giza 1 and Giza 4, and our age-models give the same chronological range (4250-3900 ± 80 BP; see Fig. 2). The primary alteration, marked by infill resulting from recent human activity in Giza 1 and the presence of grey brown silts and clays in Giza 4 due to shifting environmental conditions, is determined to have occurred during the same period (2780-2770 ± 80 BP) based on our age-models (refer to Fig. 2b). In Giza 1, human activity led to the removal of the brown deposits, whereas in Giza 4, the impact was relatively less severe, allowing for the preservation of the brown deposits (refer to Fig. 2a).

2.2. Biological indicators

A total of 109 samples were prepared for pollen analysis using standard protocols for clay deposits (Faegri and Iversen, 2020). Tablets of *Lycopodium* spores (about 20,848 spores per Tablet) were added to each sample to estimate the pollen concentration. Pollen grains and NPPs were extracted using dense-media separation processes (sodium polytungstate; 2.2 g per cm³) (Van de Bos et al., 2020; Eskola et al., 2021). Pollen grains and Non-Pollen Palynomorphs were counted under x400 and x1000 magnification using binocular transmitted light microscope. Atlases (Bonafille and Rioulet, 1980; Reille, 1992; Reille, 1995; Reille, 1998), books (Faegri and Iversen, 1980; Punt and Blackmore, 1991; Moore et al., 1991) as well as local reference slides were used for pollen identification. The NPPs were identified using published references (Shumilovskikh et al., 2023). The natural and wild varieties of Poaceae and Fabaceae were identified on the basis of key morphological criteria established by comparative studies carried out on current pollen. We examined grain pore size, annulus diameter and surface sculptures of the Poaceae family, following the methodology described by Andersen (1979), Küster (1988), and Tweddle et al. (2005). To address the potential overlap between *Hordeum vulgare* (Barley) and the wetland genus *Glyceria*, as well as between *Triticum* and *Avena*, we followed the criteria outlined by Beug (2004). These additional criteria include the presence of a more pronounced annulus protrusion, distinct outer boundary, pore location and an observation of the columellae patterns (Zhao et al., 2020). To differentiate Egyptian beans, the size of the pollen grains based on the mean values of the longest axis was used. We used specimens preserved at the ESRI Herbarium of Minufiya University (city of Sadat). Palynological slides were counted using a minimum pollen sum of 100 grains. It has been shown that a pollen count of 70-150 grains is statistically significant for a 0.90 reliability (Djamali and Cilleros, 2020). In arid and semi-arid areas, pollen contributions from the vegetation cover are low, reducing the sample pollen content (Djamali and Cilleros, 2020). The high sedimentation rates could also be a plausible explanation for the diluted pollen representation in the records of Giza floodplain (Marriner et al., 2012; Florenzano et al., 2016). All the pollen slides are housed at the IMBE laboratory (Aix-en-Provence, France).

2.3. Pollen-derived livelihood reconstruction

The datasets for the core K-1 (Fig.2a-b) is based on the average of each taxon for respective levels (average between G1 and G4). A total of 109 samples were initially collected from the Giza 1 and Giza 4 cores. To determine the average pollen and NPP counts, we considered

samples from both cores that shared the same age and lithology at each correlated level. However, it was necessary to exclude certain samples from the averaging process as they did not exhibit correlation with the corresponding sections in the other core. The second stage involved interpolating the averaged results to create a regular 50-year time increment. This interpolation process ensured consistent average chronological resolution and involved new interpolated values at additional levels situated between the counted and averaged samples. Therefore, the interpolation procedure means that the number of samples in the matrix is greater than the actual count.

The taxa were grouped into ten vegetation assemblages (Table S1). The data termed “agriculture” correspond to the sum of the cultivated plants (Poaceae cerealia, Fabaceae and Brassicaceae) while the data termed “pasture” include all the other markers of human activities (Table S1). The ten vegetation assemblages were subsequently used to create palynomorph-derived landscape patterns (PdLPs - expressed as scores) based on a cluster analysis (with paired group as algorithm and correlation as the similarity measure; Fig. S1a). Three PdLPs were defined (Fig. S1a-b and Table S1): Anthropogenic influence (Ant_{inf}), Nile influence (Nil_{inf}), and Human and climate influence ($HClim_{inf}$). The data termed “agriculture” correspond to the sum of the cultivated plants (Poaceae cerealia, Fabaceae and Brassicaceae) while the data termed “pasture” include all the other markers of human activities (Table S1). The robustness of the defined PdLPs was strengthened using a principal component analysis (PCA) ordination (Fig. S1b). A second PCA was then performed to test the ordination of samples by assessing major changes in the PdLP-scores (Fig. S1c). The first axis (PCA-Axis 1), which carries the maximum variability, has been extracted. The PdLPs influenced by the Nile floodplain and wadi margin are loaded by the negative scores of PCA-Axis 1 while the PdLP indicative of development of traditional crop agriculture, livestock breeding and pasture activities is loaded by the positive scores (Fig. S1a-c). We then transformed the PCA-Axis 1 scores using a locally weighted smoothing (LOESS smoothing; with a locally weighted scatter plot smoothing - LOWESS algorithm) and performed a bootstrap to estimate a 95% confidence band based on 1000 random replicates. The LOESS curve and the 95% confidence band (2.5-97.5 percentiles - two-tailed) were used as a proxy for the agropastoral activities (Fig. S1a-b). The PCA-Axis 1 scores were then averaged by cultural period and shown with their confidence interval (95% two-tailed confidence interval; Fig. S1c). The rate of changes in PCA-Axis 1 scores were calculated using four different time windows, 50-yr, 100-yr, 200-yr and 250-yr. The major breaks in the PCA-Axis 1 scores were highlighted using homogeneity tests (Fig. S2a-b). The raw data are illustrated as a pollen diagram (Fig. S3) and

the experimental design and statistical procedures used in the study are outlined in a flow chart (Fig. S4).

2.4. Long-term trends

The long-term trends were calculated using polynomial models (order 4, $P_{\text{value}} < 0.001$), sinusoidal regressions ($P_{\text{value}} < 0.001$), and a moving average function (500-yr). Concerning all the polynomial regressions and sinusoidal models in this study, the P_{value} is based on a F test - two-tailed, with no adjustment.

2.5. Environmental pressures

To test the impact of environmental pressures on livelihoods, we used the distribution of agropastoral activities (expressed as scores) at Giza plotted against the development of the wadi system and the rise of Nile floods. The resulting distributions were also transformed using a LOESS smoothing with a 95% confidence band, and then averaged per cultural period and shown with their confidence interval (95% two-tailed confidence interval).

2.6. Date palm

To highlight date palm cultivation, we averaged the date palm, the tamarisk and the wadi system scores by period. The data are shown with their confidence interval (95% two-tailed confidence interval). The date palm scores were then contrasted with the agropastoral activities using the same process.

2.7. Other proxies

Variations in human behaviour and livelihoods at Giza were contrasted using various high-resolution datasets, including the Nile valley population estimates (Butzer, 1976), fire activity in the West-central Nile delta (Zhao et al., 2022), the density of Eastern Sahara archaeological sites (Manning and Timpson, 2014; Kuper and Kröpelin, 2006), and the Nile level of the Khufu channel at Giza (Sheisha et al., 2022).

2.8. Statistical Analysis

All the statistical analyses were performed using R 4.1.0 (R Core Team, 2021). Past 4.08 (Hammer et al., 2001), and XL-Stat²⁰¹⁹ software (Addinsoft, 2019).

3. Results

3.1. Palynomorph-derived landscape patterns

Within the K-1 composite core (Fig. 2), we identified 61 pollen types and 13 NPP types (Table S1), grouped into three PdLPs based on their ecological affinities (Fig. S1a-c and Table S1). The PdLP Ant_{inf}, consistent with herding and farming, includes agropastoral pollen indicators, which encompasses pasture weeds, crops and field weeds (Poaceae cerealia, Fabaceae, Brassicaceae, *Artemisia*, *Rumex*, *Papaver*, *Convolvulus*, *Plantago*, *Silene*, *Asphodelus*, Cichorieae and Scrophulariaceae; Table S1). This pattern also includes agropastoral NPPs mostly indicative of anthropogenic erosion and grazing (*Glomus* type, *Pseudoschizaea*, *Pleospora*/HDV-3B, *Chaetomium* and *Neurospora*), in addition to ruderal weeds (*Carthamus*, *Centaurea*, Boraginaceae, *Salvia* and *Polygonum*), which develop on anthropologically disturbed and abandoned lands (Hill et al., 2002). Several ferns belong to the PdLP Ant_{inf}, most importantly *Riccia* as it spreads during seasonal irrigation practices (Hamdan et al., 2019). The PdLP Nil_{inf} encompasses helophytes (Cyperaceae, *Typha* and Alismataceae) and wet forbs (wild Poaceae, *Matricaria* and Liliaceae), in addition to tropical Nilotic vegetation (pollen carried downstream by the Nile from tropical areas of the watershed; Table S1). The PdLP HClim_{inf} includes date palm (*Phoenix dactylifera*), tamarisk (*Tamarix*) and drought-tolerant taxa (Amaranthaceae, Asteraceae and *Zygophyllum album*), well adapted to environments with low water availability (Shaltout et al., 2010).

We used these PdLP time-series to perform a PCA (Fig. S1c), using PCA-Axis 1 (73.5% of total variance) as a proxy for agropastoral activities (Fig. 3a-c). The negative values of PCA-Axis 1 are loaded by the PdLPs Nil_{inf} (-0.22) and HClim_{inf} (-0.27) while the positive scores are weighted by the PdLP Ant_{inf} (0.94; Fig. 3a-c). Increases in PCA-Axis 1 positive scores are thus related to the development of traditional crop agriculture, livestock breeding and pasture activities at Giza while the negative scores are indicative of environmental pressures that influenced human behaviour (Fig. 3a-c).

3.2 A story of migrations

From 6000 to 3800 BCE, during the African Humid Period, Giza was a Nile-dominated band (Sheisha et al., 2022), with a weak human impact on the landscape (PCA-Axis 1 scores average -50; Fig. 3a-c, Fig. 4a-c and Fig. S2a-b). The significant influence of increased Nile inputs in the Giza floodplain from 6000 to 3800 BCE is evident through well-established indicators such as high percentages of local wetland herbs (wild Poaceae and Cyperaceae, comprising up to 60% and 55% of the pollen sum respectively), helophyte herbs (including

Typha sp. and *Alisma* sp., accounting for approximately 17% of the total pollen sum), and the presence of Nilotic taxa (making up to 36% of the total pollen sum; Fig. S3).

After a steady decline of Cyperaceae (down to 11% of the total pollen sum) and helophytic herbs (down to 0.5% of the total pollen sum), the agropastoral activities gradually increased after 3800±80 BCE, reaching a first significant stage at 3200±80 BCE (PCA-Axis 1 scores rise from -50 to -26; Fig.3a). The record is characterized by a moderate spike in agropastoral NPPs (Table S1 and Fig. S3) and the presence of *Plantago* (4% of the pollen sum; Fig. S3). *Pseudoschizea* show a strong increase (up to 16%; Fig. S3), concurred with a parallel peak of the grazing fungal spore *Sordaria* (up to 8%). The edaphic responses to the erosive human disturbance could range from simple runoff and pastoralism to cultivation and fire activity.

We suggest a link between the Saharan migrations (Fig. 4a), population growth in the Nile valley (Fig. 4a) and the rise of agropastoral activities at Giza during the Early Dynastic period (~3200-2700±80 BCE; PCA-Axis 1 average rise from score: -26 to -6; Fig. 4b). In what is now the hyper-arid Sahara, people thrived (Fig. 4a), as portrayed by the rock carvings that depict a lush environment with Sahelian and riverine fauna and scenes of hunting, herding and grazing, and religious ceremony (di Lernia and Gallinaro, 2010). It has been shown that there were three key stages in the Sahara's recent demographic history: an important rise in trans-Saharan population levels after 9000 BCE, a temporary decline in population levels between 5600 and 4700 BCE, and a sharp population downturn at the end of the African Humid Period, between 4300 and 3200 BCE (Manning and Timpson, 2014). As a consequence of the gradual onset of extreme aridity, which affected water resources in the form of wells (Benati and Guerriero, 2021), the Eastern Sahara was abandoned by human populations with few to no permanent human settlements after 3200 BCE (Kuper and Kröpelin, 2006; Fig. 4a). The arid conditions may have forced the migration of Savannah transhumant groups towards the Nile (Fig. 4a). The increase in agropastoral activities at Giza between 3800±80 and 3200±80 BCE suggests a gradual rise in populations resulting from migrations to the Nile at the end of the African Humid Period (Fig. 3a). From the Eastern Sahara to the Nile, human behaviour was influenced by environmental pressures, leading to the foundation of an early herding community practising little farming in the pastures of Giza (Fig. 4b).

3.3 Development of herding and farming at Giza

Our reconstruction suggests that Giza was gradually transformed into an agropastoral landscape during the Egyptian Archaic Period (Fig. 4a-c, Fig. S2a-b). Emerging shortly before and during the reign of King Hotepsekhemwy, the founder of the Second Dynasty

(2825 BCE; Shaw, 2000), herding and farming increased during the reign of King Khasekhemwy (2696-2654 BCE; Bronk-Ramsey et al., 2010), reaching a first plateau (PCA-Axis 1 score of 34.5) during the reign of King Djoser (2676-2643 BCE; Bronk-Ramsey et al., 2010), the founder of the Old Kingdom (Fig. 3a). The rise in agropastoral activities at Giza appears to be synchronous with the development of human-induced fire activity on the west-central Nile Delta (Zhao et al., 2022; Fig. 3b) and population increases in the Nile Valley (Butzer, 1976; Fig. 3a). When the PCA-Axis 1 scores are averaged per period, the major rise of agropastoralism during the Old Kingdom becomes evident (from -40 to 40 on the PCA-Axis 1 scores; Fig. 3c).

3.4. Agriculture and livestock during the Old Kingdom

Despite an environmental transition at Giza from a Nile-dominated landscape (Sheisha et al., 2022) to well-drained pastures during the Second Dynasty (2825-2686 BCE; Shaw, 2000; Fig. 4b), with an important rate of change in agropastoral activities (~1635 - 50-yr window, and up to ~2160 - 100-yr window; Fig. 4c), our reconstruction suggests that agriculture was practiced more intensively during the Old Kingdom (ca. 2686-2160 BCE) than during the previous phases (agriculture average score of 28.2; Fig. 3c). The Old Kingdom's palynological spectra show several abrupt peaks of the agropastoral pollen and NPPs (Table S1 and Fig. S3). The Fabaceae increase to an average of 20% and Cerealia to an average of 3% (Fig. S3). Farming activities were most probably dominated by cereals, emmer, wheat and barley, and by legumes and fodder (Fig. 4b; Fig. S3). The ferns, mainly *Riccia*, flourished during this period (26-47 %). These significant values are consistent with the development of irrigation techniques. These techniques promote the regular deposition of well-drained, muddy soil in targeted regions during intermittent droughts or excessive submergence in neighboring areas. These high values support the emergence of early irrigation which boosted the frequent deposition of well drained muddy sediments (Hamdan et al., 2019). The palynological spectra from the Old Kingdom exhibit notable presence of erosion indicators, with *Glomus*-type comprising up to 25% and *Pseudoschizae* up to 9%. Additionally, dung indicators such as *Sordaria* can be observed, ranging from 6%, and *Pleospore* up to 2%. Fire indicators like *Neurospora* are also evident, reaching up to 5% (Fig. S3).

Agriculture seems to have been less developed than pastoral activities on the Giza Plateau during the Old Kingdom as the scores of cereals and field weeds (average score: 28.6 ± 1.3) never attain those of the pastoral indicators (average score: 83.1 ± 4.9 ; Fig. 4b). The cultural heritage of the early herding community at Giza seems to have persevered and endured

throughout the Old Kingdom. During the building of the necropolis, from King Khufu to King Menkaure (from 2613 to 2524 BCE, taking the first regnal year of each king; Bronk-Ramsey et al., 2010), Giza was mainly a pastoral landscape (pasture score average: 75.27; Fig. 3a and Fig. 4b), with probable sundry herds located near the construction sites. As depicted by our palaeoecological reconstructions, vast pastures were used to feed these herds. Agriculture was a secondary activity (agriculture score average: 28.42; Fig. 4b), restricted to narrow bands located on the fertile lands seasonally flooded by the Nile. The builders of the pyramids enjoyed access to a wide range of goods derived from livestock, including protein, milk, meat, wool, and leather. However, they also partially relied on imports from other regions to supplement their grain supply. We suggest that cereals were easily transported to the construction sites and stocked, because they do not perish quickly, whereas the longevity of livestock foods is affected by conservation issues. This observation could provide an explanation for the concentration of herds in proximity to the pyramids, while local cereal agriculture may have been relatively underdeveloped.

3.5. *The waxing and waning of herds and farming*

Egypt became politically unstable (Shaw, 2000, Weiss, 2017) during the First Intermediate Period (onset at 2240-2186 BCE; duration 137 to 195 years; Bronk-Ramsey et al., 2010) but Giza remained a favourable area for livestock breeding and agriculture with (Fig. 3a), with an average PCA-Axis 1 score of 49.8 ± 5.6 (Fig. 3c). Whereas the level of the Khufu branch locally dropped by ~10% compared to the Great Pyramid stage (first low point at 2225 ± 80 BCE; Sheisha et al., 2022), this process seems to have had no aftermath on local production as pastoral activities (score of 81.1) and cereal agriculture (score of 31.1) continued to develop, reaching higher levels than those recorded during the Old Kingdom (PCA-Axis 1 score of 39.3 ± 1.6 ; Fig. 3c).

At Giza, the early herding community peaked during the Middle Kingdom (~2040-1780±80 BCE) but started to decline during the Second Intermediate Period, from 1775 ± 80 to 1575 ± 80 BCE (Fig. 3a). The Middle Kingdom's pollen and NPP values indicate major human impacts on the landscape, with peaks of agropastoral pollen-indicators (up to 56%; Table S1; Fig. S3), agropastoral NPP-indicators (up to 34%; Table S1; Fig. S3) and *Riccia* (up to 6%; Fig. S3). Our findings reveal that throughout the majority of the Old Kingdom and Middle Kingdom (2696-1780 ±80 BCE), the presence of Wadi indicators (Table S1) remained below 25%. Similarly, the representation of date palm was observed to be below 5% (Fig. S3). During this period, the PdLP Hclim_{inf} is characterised by low scores (Table S1, Fig. S3). This suggests

that the agropastoral society at Giza experienced relatively low environmental pressures, as indicated by our estimation of optimal environmental conditions for human activity (Fig. 5a-c).

The first phase of the New Kingdom, from King Thutmose I (first regnal year 1520-1507 BCE; Bronk-Ramsey et al., 2010) to King Seti I (1307-1296 BCE; Bronk-Ramsey et al., 2010), is marked by an increase in agropastoralism as attested by high values of agropastoral indicators (up to 47%; Table S1 and Fig. S3). Wild Poaceae peak (up to 50%) is most likely a by-product of the flourishing cultivation activities. From 1275±80 BCE, human activities gradually waned, declining by about 40% relative to the Middle Kingdom (from average score 65.9±4.9 to 29.5±9.5; Fig. 3c and Fig. S2a-b).

3.6. Desertification and a major change in human behaviour

After ~1275±80 BCE, pollen spectra show an abrupt decline of the PdLP Nil_{inf} scores (Table S1). In contrast, all the pollen types associated with the PdLP HCliminf (Table S1) exhibit peaks surpassing 48% (Fig. S3), suggesting a substantial aridification of the Khufu channel's vicinity and a retreat of its floodplain. Our record shows that pastoral activities first declined around 1275±80 BCE (from ~68 to ~17 at 825±80 BCE; Fig. 4b), and beginning around 925±80 BCE, traditional agriculture was also affected (from ~23 to ~3 at 525±80 BCE; Fig. 4b) reaching similar values to those recorded when the Nile flooded Giza and transformed the area into a permanent swamp before 2850±80 BCE (Fig. 4b and Fig. 5b). The indicators of human disturbance, agropastoral NPPs and ferns, show a drop down to 4% and 10% respectively (Fig. S3).

The palaeoecological data document a major change in human behaviour beginning around 1075±80 BCE [rate of change at 1025±80 BCE: -615 (100-yr window); rate of change at 925±80 BCE: -1221 (200-yr window) and rate of change at 875±80 BCE: -1221 (250 yr window); Fig. 4c]. Agropastoralism declined in Giza (Fig. 3c) from the Third Intermediate Period to the Late period (~1053-335 BCE; Shaw, 2000), when the environment became drier (Fig. 3b, Fig. 4b-c and Fig. S2; Kaniewski et al., 2015, 2020). Our reconstruction shows that the environmental attractiveness of Giza for herding and farming during previous periods (Old Kingdom, Middle Kingdom, and most of the New Kingdom) was intricately linked to a set of optimal environmental conditions favourable to human activity (Fig. 5a-c). The marked decrease in traditional farming (from ~25 at 1075±80 BCE to ~8 at 375±80 BCE; Fig. 5a-b) after the death of Rameses XI (first regnal year 1110-1100 BCE; Bronk-Ramsey et al., 2010) seems to be linked to a sharp drop of the Khufu branch's level (Fig. 4b; Sheisha et al., 2022)

and the development of a wadi landscape (Fig. 5a) , both leading to a waning of the population in the Nile valley (Butzer, 1976; Fig. 3a). The Wadi indicators (see PdLP Hclim_{nf}; Table S1) rise to a score of (43%; Fig. S3) and the date palm zone expands (13%; Fig. S3). The elevated PdLP Hclim_{nf} scores (Table S1, Fig. S3) highlight the pronounced environmental pressures experienced by the agropastoral communities in Giza. This is vividly illustrated in our analysis, where we estimate the optimal environmental conditions for human activity (Fig. 5a-c). The small groups that continued to populate Giza adapted and developed a new form of agriculture based on date palm, a drought-tolerant tree (Fig. 5c and Fig. 6 a-b). For ~700 years, the area remained a sparsely populated wadi with scattered clusters of tamarisks and significant stands of date palms (Fig. 6a-b). This period was the first to be different since the settlement of early herding communities 5200 years ago.

3.7. Early herding communities' cultural heritage

The Greek conquest of Egypt marks the return of pastoral communities to Giza (pasture score: ~78; Fig. 4b-c), a cultural heritage that seems to be rooted in the tradition of early land-use. The pastoral activities and traditional grain agriculture redeveloped during the Ptolemaic period (375±80 BCE; Fig. 3c and Fig. S2a-b), characterized by extensive riverine pastures (Fig. 4b). A first peak in herding was reached in 275-225±80 BCE, under the reigns of Ptolemy the Great (284-246 BCE; Shaw, 2000) and Ptolemy III (246-221 BCE; Shaw, 2000). While agropastoralism declined (25±80 BCE) when Rome conquered Egypt, grain agriculture redeveloped attaining a high plateau from 275±80 to 625±80 CE (average score: 38±1.7; Fig. 4c and Fig. 5c). During the Roman period, we found that the rates at which the Giza landscape changed was the highest of all the record [rate of change at 75±80 CE: ~2188 (100-yr scale); rate of change at 175±80 CE: ~5568 (200-yr scale); rate of change at 225±80 CE: ~7245 (250-yr scale); Fig. 4c]. Though pastures steadily increased until 1075±80 CE, agriculture declined sharply following the Muslim conquest of Egypt in 641 CE (Fig. 4b). The last decrease in agropastoralism at Giza (since 1075±80 BCE) corresponds to the emergence and urban expansion of Cairo from the Fatimid to the Mamluk periods (Fig. 3a). Two major drops occurred, the first during the Crusader raid in 1168 CE, altering the occupation of the territory, and the second when the city's economic status declined after Vasco da Gama discovered a sea route around the cape of Good Hope (1497-1499 CE), allowing traders to circumvent Cairo (Fig. 3a).

4. Discussion

4.1. Nile River

Egypt stands as a notable nation within the Afro-Asiatic monsoon belt, which witnessed the rise of early states during the 4th and early 3rd millennia BCE, largely attributed to climate changes. The early livelihood shifts in ancient Egypt could be perceived as adaptative social-ecological responses to environmental changes, between the fluctuating flow of the Nile River and the oscillating boundaries of the desert margin (Butzer, 1976; Hassan, 1997; Marriner et al., 2012; Zhao et al., 2020, 2021, 2022). The onset of the Holocene brought a humid environment to North Africa, which played a crucial role in facilitating the development of Egyptian civilization, even without the immediate need for agriculture (Butzer, 1976; 2020; Hassan, 1984; Wenke, 1990; Wetterstrom, 1993; Barker, 2006; Bellwood 2005). During the African Humid Period, the Egyptian Western Desert comprised a cluster of semi-arid oases covered with grassland and scrubs, open to transhumance groups (Foley, 1994; Nicoll, 2004; Brooks, 2006; Kröpelin et al. , 2008; Shanahan et al., 2015; Menviel et al., 2021). However, the favorable environmental conditions came to an end in the mid-4th millennium BCE, as the Egyptians encountered food shortages caused by climate change-induced desertification in the region. To mitigate the impact of these challenges, they likely turned to the importation of domesticated products from the Levant, ensuring their sustenance amidst the changing climate (Shirai, 2010, Pennington et al 2020). By the end of the African Humid Period (~3500 BCE; Shanahan et al., 2015; Tierney et al., 2017), the swampy waterscapes of Giza transitioned into a fertile area, fed annually by more modest Nile floods (Sheisha et al., 2022). The newly emerged landscapes at Giza, conducive to grazing due to nutrient-rich windrows, created an optimal refuge for the transhumant groups who migrated from the drought-affected savannah to the Nile (Nicoll, 2004; Brooks, 2006; Kröpelin et al., 2008; Shanahan et al., 2015; Menviel et al., 2021; Fig. 4a and Fig. 5a-b). These migrations (Kuper and Kröpelin, 2006; Manning and Timpson, 2014) and the resulting demographic changes (Butzer, 1976) led to the emergence of an early herding community practising little farming in Giza, replicating their traditional mode of subsistence inherited from their lifestyle in the Sahara (Kuper and Riemer, 2013). The persistence of this lifestyle can be perceived as a cultural transmission from the Sahara towards the Nile.

The concordance between the earliest recorded agropastoral activities at Giza and estimates of population growth in the Nile Valley (up to several hundred thousand people in the Early Dynastic Period - ~3100-2700 BCE; Butzer, 1976) could suggest that Giza was one of the main receivers of the migrations out of the Sahara during the Holocene (Fig. 4a). Many sites in Lower Egypt have recorded the same process of colonization and human modification of

land, as attested at sites like El Omari and Merimde Beni Salama (Debono and Mortensen, 1990; Eiwanger, 1992; Köhler, 2011; Rowland, J.M., Bertini, L.C., 2016), and by increasing fire activities at Sais on the Nile Delta (Zhao et al., 2022; Fig 3b).

4.2. Old Kingdom and First Intermediate Period

The agropastoral activities at Giza intensified following the onset of the Old Kingdom (2675±80 BCE; Fig. 3a-c), reaching a first plateau during the construction of the pyramid complex with an agriculture dominated by cereals (emmer, wheat and barley), legumes, pulses and fodder (Fig. 3a-b and Fig 4b). This type of farming, based on traditional crops, has also been recorded by observations deriving from mudbricks (eastern cemetery of Khufu's pyramid and temple of Menkaure's pyramid; Ayyad et al., 1991) and archaeological artefacts (Khentkawes town; Malleson, 2016). Macrofossil investigations of Egyptian Early Dynastic and Old Kingdom sites near Giza have also recorded the same crops. Carbonized barley (*Hordeum spontaneum*), emmer (*Triticum diccicum*) and club wheat (*Triticum compactum*) were discovered in Merimde, North Giza (Krzyzaniak, 1977; Stemler, 1980) and Pulses, cereals grains, and threshing residues were unearthed at Maadi on the other bank of the Nile (Caneva et al., 1987).

Our long-term reconstruction indicates that agricultural activities at Giza were included in a vast pastoral landscape (Fig. 3a and Fig. 4b) where herds (e.g., sheep, goats, cattle) grazed near the pyramids under construction, ensuring workers a permanent and local supply of protein (alongside those imported and complementing other sources such as fish and pulses). The labour-intensive construction of the necropolis and food preservation issues appear to have influenced human behaviour, favouring livestock and neglecting agriculture, with cereal-based produce being more easily imported and conserved (Fig. 4b). The excavations conducted at Heit El Ghorab, also known as the city of workers, have yielded valuable insights through the analysis of animal bone remains. These findings provide compelling evidence that the pyramid builders relied heavily on a diet abundant in meat, with cattle, sheep, and goat being the predominant sources of protein (Kokabi, 1980; Lehner 1992; 1993; 2002; Redding, 1992; 2013). The textual records further strengthen our hypotheses, suggesting that by the Old Kingdom, the Nile Delta's landscapes became increasingly conducive to cattle production (Kees, 1961; Butzer, 1976; Ghoneim, 1977). While the demise of the Old Kingdom and the emergence of the First Intermediate Period at 2240-2186 BCE (Bronk-Ramsey et al., 2010) seem to be related to a series of low floods in the Nile (Bárta,

2019; Burn, 2021), local agropastoralism at Giza does not show a noticeable decline. Local herders adapted by adjusting the local food production and water supply.

4.3. Middle Kingdom

The Middle Kingdom (~2040-1780±80 BCE) was a prosperous agropastoral period at Giza (Fig. 3a), with ideal conditions for herding and agriculture (Fig. 5c); these conditions persisted until the second half of the New Kingdom (Fig. 3c). The land-use pattern established by local communities was supported by optimal and regular floods of the Khufu branch of the Nile (Sheisha et al., 2022; Fig. 4b and Fig. 5b). This period of prosperity could also be related to an evolution of human behaviour, particularly through a better management of the floodplain and the development of more efficient irrigation systems as depicted in the Memphite region where, from the reigns of Senusret II (first regnal year 1890-1868 BCE; Bronk-Ramsey et al., 2010) to Amenemhat III (first regnal year 1844-1820 BCE; Bronk-Ramsey et al., 2010), massive irrigation projects such as the deepening and damming of the Bahr Yusuf were undertaken (Bell, 1975; Erman, 2017).

4.4. New Kingdom and Third Intermediate Period

This context evolved at the end of the New Kingdom. The Khufu branch of the Nile waned to a small channel from 1275±80 to 375±80 BCE (Sheisha et al., 2022; Fig. 4b) referred to as the "Maaty" canal (Bunbury and Jeffreys, 2011). As the wadi developed (Fig. 5a), the herder communities abandoned Giza and moved towards wetter areas of the valley. The same narrative of abandonment has been proposed for several delta sites, like the evacuation of the royal residence at Pi-Ramesses (Avaris) due to the decline of the Pelusiac branch of the Nile after ~1200 BCE (Hodgkinson, 2007; Bietak and Forstner-Müller, 2011). Egypt tumbled into the Third Intermediate Period within less than two centuries, and the Meshwesh Libyans ruled for about 400 years (Bennett, 2019). Giza became a neglected and marginal area devoid of grain farming. To adapt to these drier environmental conditions (Fig. 6a), the small groups of herders who remained in the wadi around Giza developed a different mode of subsistence based on date palm cultivation (Fig. 6b), suggesting both social and cultural evolution.

4.5. From the Ptolemaic era to the foundation of Cairo

Traditional agropastoral activities in Giza were reintroduced during the Ptolemaic era, associated with a new population surge in the valley (Fig. 3a). A previous study suggested that the Nile level at Giza was shallow when Alexander the Great conquered Egypt (Sheisha

et al., 2022). However, the Ptolemies (305-30 BCE) adapted to a decline in Nile levels and undertook several irrigation projects in Egypt, such as the reclamation of vast land areas in the Fayum and the excavation of irrigation canals (Hölbl, 2013; Koopman et al., 2016). The Ptolemaic policies for agriculture and an improved control of the hydrological system could explain the partial restoration of human activities at Giza beginning in the fourth century BCE. Grain agriculture developed strongly during the Roman period, when Egypt was the Mediterranean's breadbasket, producing a reliable supply of wheat at a time when food surpluses were extremely important in maintaining the stability of the Roman Empire. Following the Muslim conquest of Egypt in 641 CE, and until the foundation of Cairo, pasture activities steadily increased, rapidly becoming dominant. During this period, herding was reintroduced at Giza, much like the earliest settlers 5200 years ago. A millennium ago, the cultural transmission of the Saharan way of life remained profoundly ingrained in the lifestyles of the people in Giza. This connection highlights the enduring influence of Saharan cultural practices and their profound impact on the behavior and traditions of the inhabitants of Giza.

5. Conclusion

Palaeobotanical studies play a crucial role in unraveling the evolution of past cultural landscape in archaeological contexts. In this study, we employed biological indicators such as pollen and NPPs to probe the history of herding and farming at Giza, from the Predynastic period to the Islamic era (7980±80 BCE to 375±80 CE). Within the K-1 composite core, our analysis identified a rich array of 61 pollen types and 13 NPP types. These taxa were classified into ten distinct vegetation assemblages and three primary PdLPs, elucidating the ancient plant communities at Giza. Our findings reveal that agropastoral activities gradually expanded from 3800±80 BCE, with a significant upsurge around 3200±80 BCE. This increase directly corresponds to increasing population numbers, potentially driven by migrations from the Eastern Sahara to the Nile, and the establishment of early herding communities practicing limited farming in the pastures of Giza during the Early Dynastic period. While agriculture experienced intensification during the Old Kingdom, our reconstruction highlights that crop cultivation at Giza remained limited within the vast pastoral landscape, where herds such as sheep, goats, and cattle grazed in proximity to the pyramids. The Middle Kingdom (~2040-1780±80 BCE) constituted a prosperous agropastoral period at Giza, characterized by favorable conditions for both herding and agriculture. These conditions persisted until the latter part of the New Kingdom. However, towards the end of the New Kingdom, the Khufu

branch of the Nile receded, resulting in the development of a wadi, which led to the abandonment of Giza by the herding communities. To adapt to the drier environmental conditions, the small groups of herders who remained in the wadi around Giza underwent a shift in subsistence strategies, focusing on date palm cultivation, signifying significant social and cultural evolution. During the Ptolemaic era, traditional agropastoral activities were reintroduced at Giza, coinciding with a new surge in population in the region. Local grain agriculture witnessed strong growth during the Roman period. Following the Muslim conquest of Egypt in 641 CE, and until the foundation of Cairo, pastoral activities steadily increased, ultimately becoming dominant in the region.

Author statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

All data needed to evaluate the conclusions in the paper are present in the paper and/or the Supplementary Materials (Raw data file).

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Appendix A. Supplementary data

The following is the Supplementary data to this article.

Figs. S1-3

Tabulated Raw Data

References

- Addinsoft, XLSTAT Statistical. Data Analysis Solution (2019), Long Island, NY, USA.
- Andersen, S.T., 1979. Identification of wild grass and cereal pollen (fossil pollen, annulus diameter, surface sculpturing). *Danmarks Geologiske Undersoegelse, Aarbog.*
- Attia, E.A.E., Marinova, E., Fahmy, A.G., Baba, M., 2018. Archaeobotanical studies from Hierakonpolis: Evidence for food processing during the predynastic period in Egypt. In: Mercuri, A.M., D'Andrea, A.C., Fornaciari, R., Höhn, A. (Eds.), *Plants and people in the African past*. Springer, Cham, pp. 76-89.
- Ayyad, S., Krzywinski, K., Pierce, R., 1991. Mudbrick as a bearer of agricultural information: an archaeopalynological study. *Norw. Arch. Rev.* 24, 77-9.
- Bárta, M., 2019. *Analyzing collapse: the rise and fall of the Old Kingdom*. American University in Cairo Press, Cairo.
- Bell, B., 1975. Climate and the history of Egypt: the Middle Kingdom. *A.J.A.* 79, 223-269.
- Benati, G., Guerriero, C., 2021. Climate change and state evolution. *Proc. Natl. Acad. Sci. U.S.A.* 118, e2020893118. <https://doi.org/10.1073/pnas.2020893118>
- Bennett, J.E., 2019. *The Archaeology of Egypt in the Third Intermediate Period*. Cambridge University Press, Cambridge.
- Beug, H.J., 2004. *Leitfaden der pollenbestimmung für mitteleuropa und angrenzende gebiete*. Pfeil, München.
- Bietak, M., Forstner-Müller, I., 2011. The topography of New Kingdom Avaris and Per-Ramesses. In: Collier, M., Snape, S.R. (Eds.), *Ramesside Studies in honor of K.A. Kitchen*. Rutherford Press, USA, pp. 11-50.
- Blaauw, M., 2010. Methods and code for 'classical' age-modelling of radiocarbon sequences. *Quat. Geochronol.* 5, 512-518.

- Bonnefille, R., Riollet, G., 1980. Pollens des savanes d'Afrique Orientale. Editions du Centre National de la Recherche Scientifique, Paris.
- Bronk-Ramsey, C., Dee, M.W., Rowland, J.M., Higham, T.F., Harris, S.A., et al., 2010. Radiocarbon-based chronology for Dynastic Egypt. *Science* 328, 1554-1557.
- Brookfield, M., 2011. The desertification of the Egyptian Sahara during the Holocene (the last 10,000 years) and its influence on the rise of Egyptian civilization. In: Martini, I., Chesworth, W. (Eds.), *Landscapes and societies: Selected cases*. Springer, Dordrecht, pp. 91-108.
- Brooks, N., 2006. Cultural responses to aridity in the Middle Holocene and increased social complexity. *Quat. Int.* 151, 29-49.
- Bunbury, J., Jeffreys, D., 2011. Real and literary landscapes in ancient Egypt. *Camb. Archaeol. J.* 21, 65-76.
- Burn, J.W., 2021. A river in 'drought'? Environment and cultural ramifications of Old Kingdom climate change, BAR Publishing, Oxford.
- Butzer, K., 1976. *Early hydraulic civilization in Egypt: A study in cultural ecology*. University of Chicago Press, Chicago.
- Butzer, K., Butzer, E., Love, S. 2013. Urban geoarchaeology and environmental history at the Lost City of the Pyramids, Giza: synthesis and review. *J. Archaeol. Sci.* 40, 3340-3366.
- Caneva, I., Frangipane, M., Palmieri, A., 1987. Predynastic Egypt: new data from Maadi. *Afr. Archaeol.* 5, 105-114.
- Debono, F., Mortensen, B., 1990. El Omari: a Neolithic settlement and other sites in the vicinity of Wadi Hof, Helwan with appendixes on geology. P. von Zabern, Mainz am Rhein.
- di Lernia, S., Gallinaro, M., 2010. The date and context of Neolithic rock art in the Sahara: engravings and ceremonial monuments from Messak Settafet (southwest Libya). *Antiquity* 84, 954-975.
- Djamali, M., Cilleros, K., 2020. Statistically significant minimum pollen count in Quaternary pollen analysis; the case of pollen-rich lake sediments. *Rev. Palaeobot. Palynol.* 275, 104156. <https://doi.org/10.1016/j.revpalbo.2019.104156>
- Edwards, J.F., 2003. Building the Great Pyramid: probable construction methods employed at Giza. *Technol. Cult.* 44, 340-354.
- Eiwanger, J., 1992. Merimde-Benisalâme III. Die Funde der jüngeren Merimdekultur, Mainz.

- El Mahdy Othmana, O., Silva, D., 2016. Sheep diversity of five Egyptian breeds: Genetic proximity revealed between desert breeds. *Local sheep breeds diversity in Egypt. Small Rumin. Res.* 144, 346-352.
- Erman, A., 2017. *Ancient Egyptian literature: A collection of poems, narratives and manuals of instructions from the third and second millennia BC.* Routledge Revivals, London.
- Eskola, T., Kontio, R., Lunkka, J.P., 2021. Comparison between modified LST Fastfloat and conventional HF methods for pollen preparation in highly minerogenic sediments. *Bull. Geol. Soc. Finland* 93, 5-18.
- Fægri K., Iversen I., 1989. *Textbook of pollen analysis (4th Ed.)*. John Wiley and Sons, Chichester.
- Florenzano, A., Mercuri, A.M., Altunoz, M., Garcea, E.A.A., 2016. Palynological evidence of cultural and environmental connections in Sudanese Nubia during the Early and Middle Holocene. *Quat. Int.* 412, 65-80.
- Garnsey, P., 1988. *Famine and food supply in the Graeco-Roman world.* Cambridge University Press, Cambridge.
- Ghoneim, W., 1977. *Die ökonomische Bedeutung des Rindes im alten Ägypten.* Habelt, Bonn.
- Hamdan, M.A., Hassan, F.A., Flower, R.J., Leroy, S.A.G., Shallaly, N.A., et al., 2019. Source of Nile sediments in the floodplain at Saqqara inferred from mineralogical, geochemical, and pollen data, and their palaeoclimatic and geoarchaeological significance. *Quat. Int.* 501, 272-288.
- Hamdan, M.A., Martinez, S.M., Garcia Vallès, M.T., Nogués, J.M., Hassan, F.A., et al., 2014. Ancient Egyptian pottery from the subsurface floodplain of the Saqqara–Memphis Area: its mineralogical and geochemical implications. *Archaeometry* 56, 987-1008.
- Hamdy, R.S., Fahmy A.G., 2015. The archaeobotanical remains of KV 63, Luxor, Egypt. *Atti. Soc. Nat. Mat. Modena* 146, 33-35.
- Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological statistics software package for education and data analysis. *Palaeontol. Electron.* 4, 9, http://palaeo-electronica.org/2001_1/past/issue1_01.htm
- Hassan, F.A., 1997. The dynamics of a riverine civilization: a geoarchaeological perspective on the Nile Valley, Egypt. *World Archaeol.* 29, 51-74.
- Hill, M.O., Roy, D.B., Thompson, K., 2002. Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. *J. Appl. Ecol.* 39, 708-720.
- Hodgkinson, A.K., 2007. July. The Final Phase of Per-Ramesses: The History of the City in the Light of its Natural Environment. In: Cannata, M. (Ed.), *Current research in*

- Egyptology 2006: Proceedings of the seventh annual symposium, Oxbow Books Limited, Oxford, p.99-115.
- Hölbl, G., 2013. A history of the Ptolemaic empire. Routledge, London.
- Ikram, S., 1995. Choice cuts: meat production in ancient Egypt. Peeters Publishers, Leuven.
- Janick, J., 2002. Ancient Egyptian agriculture and the origins of horticulture. *Acta Hort.* 582, 23-39.
- Janick, J., 2005. The origin of fruits, fruit growing, and fruit breeding. *Plant Breed. Rev.* 25, 255-320.
- Kaniewski, D., Guiot, J., Van Campo, E., 2015. Drought and societal collapse 3200 years ago in the Eastern Mediterranean: a review. *WIREs Clim. Change* 6, 369-382.
- Kaniewski, D., Marriner, N., Cheddadi, R., Fischer, P.M., Otto, T., et al., 2020. Climate change and social unrest: A 6,000-year chronicle from the eastern Mediterranean. *Geophys. Res. Lett.* 47, e2020GL087496. <https://doi.org/10.1029/2020GL087496>
- Kees, H., 1961. ancient Egypt: a cultural topography. University of Chicago press, Chicago.
- Köhler, E.C., 2011. Neolithic in the Nile Valley (Fayum A, Merimde, el-Omari, Badarian). *Archéo-Nil.* 21, 17-20.
- Kokabi, V.M., 1980. Tierknochenfunde aus giseh/gypten. *Annalen des Naturhistorischen Museums in Wien* 83, 519-537.
- Koopman, A., Kluiving, S., Holdaway, S., Wendrich, W., 2016. The effects of Holocene landscape changes on the formation of the archaeological record in the Fayum Basin, Egypt. *Geoarchaeology* 31, 17-33.
- Kröpelin, S., Verschuren, D., Lézine, A.M., Eggermont, H., Cocquyt, C., et al., 2008. Climate-driven ecosystem succession in the Sahara: the past 6000 years. *Science* 320, 765-768.
- Krzyzaniak, L., 1977. Early Farming Cultures on the Lower Nile. The Predynastic Period in Egypt. Varsovie: Edition Scientifiques de Pologne. Travaux du Centre Archéologique Méditerranéenne de l'Académie Polonaise des Sciences, 21.
- Kuper, R., Kröpelin, S., 2006. Climate-controlled Holocene occupation in the Sahara: motor of Africa's evolution. *Science* 313, 803-807.
- Kuper, R., Riemer, H., 2013. Herders before pastoralism: Prehistoric prelude in the Eastern Sahara. In: Bollig, M., Schnegg, M., Wotzka, H.P. (Eds.), *Pastoralism in Africa: past, present and future*. Berghahn Books, Oxford, p. 31-65.
- Küster, H., 1988. Vom werden einer kulturlandschaft: vegetationsgeschichtliche studien am auerberg (Südbayern). *Acta Humaniora*, Weinheim.

- Lehner, M., 1992. Excavations at Giza: 1988–1991. In: Sumner W.M. (Ed.), *The Oriental Institute News and Notes* 135 (Fall): 1–9.
- Lehner, M., 1993. “Giza,”. In: W. M. Sumner (Ed.), *The Oriental Institute 1991–1992 Annual Report* (Chicago: The Oriental Institute): 56–67.
- Lehner, M., 2002. The Pyramid Age Settlement of the Southern Mount at Giza, *JARCE* 39, 27–74.
- Lehner, M., 2009. Giza Plateau Mapping Project, seasons 2006-2007: preliminary report (Giza occasional papers 3). Ancient Egypt Research Associates, Michigan University.
- Lehner, M., Tavares, A., 2010. Walls, ways and stratigraphy: signs of social control in an urban footprint at Giza. In: Bietak, M. (Ed.), *Cities and urbanism in ancient Egypt*. Verlag der Österreichische Akademie der Wissenschaften, Vienna, p. 171-216.
- Lehner, M., Wetterstrom, W., 2007. Giza Reports, I. Project history, survey, ceramics, and main street. Ancient Egypt Research Associates, Michigan University.
- Macklin, M.G., Toonen, W.H., Woodward, J.C., Williams, M.A., Flaux, C., et al., 2015. A new model of river dynamics, hydroclimatic change and human settlement in the Nile Valley derived from meta-analysis of the Holocene fluvial archive. *Quat. Sci. Rev.* 130, 109-123.
- Macklin, M.G., Woodward, J.C., Welsby, D.A., Duller, G.A., Williams, F.M., et al., 2013. Reach-scale river dynamics moderate the impact of rapid Holocene climate change on floodwater farming in the desert Nile. *Geology* 41, 695-698.
- Malleson, C., 2016. Informal intercropping of legumes with cereals? A re-assessment of clover abundance in ancient Egyptian cereal processing by-product assemblages: archaeobotanical investigations at Khentkawes town, Giza (2300-2100 BC). *Veget. Hist. Archaeobot.* 25, 431-442.
- Manning, K., Timpson, A., 2014. The demographic response to Holocene climate change in the Sahara. *Quat. Sci. Rev.* 101, 28-35.
- Marriner, N., Flaux, C., Morhange, C., Kaniewski, D., 2012. Nile Delta’s sinking past: Quantifiable links with Holocene compaction and climate-driven changes in sediment supply? *Geology* 40, 1083-1086.
- Menviel, L., Govin, A., Avenas, A., Meissner, K.J., Grant, K.M., et al., 2021. Drivers of the evolution and amplitude of African Humid Periods. *Commun. Earth Environ.* 2, 237. <https://doi.org/10.1038/s43247-021-00309-1>
- Moens, M.F., Wetterstrom, W., 1988. The agricultural economy of an Old Kingdom town in Egypt's west Delta: insights from the plant remains. *J. Near. East.* 47, 159-173.

- Moore, P.D., Webb, J.A., Collison, M.E., 1991. *Pollen Analysis* (2nd Ed.). Blackwell Scientific Publications, Oxford.
- Moustafa, A., Fahmy, A.G., Hamdy, R.S., 2018. Archaeobotanical study at the early dynastic cemetery in Helwan (3100–2600 BC), Egypt: Plant diversity at early dynastic Memphis. In: Mercuri, A.M., D’Andrea, A.C., Fornaciari, R., Höhn, A. (Eds.), *Plants and people in the African past*. Springer, Cham, pp. 13-39.
- Nicoll, K., 2004. Recent environmental change and prehistoric human activity in Egypt and Northern Sudan. *Quat. Sci. Rev.* 23, 561-580.
- Perters-Destéract, M., 2005. *Pain, bières et toutes bonnes choses. L’alimentation dans l’Égypte ancienne*. Du Rocher Editions, Monaco.
- Punt, W., Blackmore, S., 1991. *The Northwest European Pollen Flora VI*. Elsevier, Amsterdam.
- R Core Team, 2021. *R: A language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria. <https://www.R-project.org/>.
- Redding, R.W., 1992. Egyptian Old Kingdom patterns of animal use and the value of faunal data in modeling socioeconomic systems. *Paléorient* 18, 99-107.
- Reille, M., 1992. *Pollen et Spores d’Europe et d’Afrique du Nord*. Laboratoire de botanique historique et palynologie, CNRS, Marseille.
- Reille, M., 1995. *Pollen et Spores d’Europe et d’Afrique du Nord. Sup. I*. Éditions du Laboratoire de botanique historique et palynologie, Marseille.
- Reille, M., 1998. *Pollen et Spores d’Europe et d’Afrique du Nord. Sup. II*. Éditions du Laboratoire de botanique historique et palynologie, Marseille.
- Rowland, J.M., Bertini, L.C., 2016. The Neolithic within the context of northern Egypt: New results and perspectives from Merimde Beni Salama. *Quat. Int.* 410, 160-172.
- Schafberg, R., Swalve, H.H., 2015. The history of breeding for polled cattle. *Livest. Sci.* 179, 54-70.
- Shaltout, K.H., Sharaf El-Din, A., Ahmed, D.A., 2010. *Plant life in the Nile Delta*. Tanta University Press, Tanta.
- Shanahan, T.M., McKay, N.P., Hughen, K.A., Overpeck, J.T., Otto-Bliesner, B., et al., 2015. The time-transgressive termination of the African Humid Period. *Nat. Geosci.* 8, 140-144.
- Shaw, I., 2000. *The Oxford History of Ancient Egypt*. Oxford University Press, Oxford.
- Sheisha, H., Kaniewski, D., Marriner, N., Djamali, M., Younes, G., et al., 2022. Nile waterscapes facilitated the construction of the Giza pyramids during the 3rd millennium

- BCE. Proc. Natl. Acad. Sci. U.S.A. 119, e2202530119.
<https://doi.org/10.1073/pnas.2202530119>
- Shumilovskikh, L.S., Shumilovskikh, E.S., Schlütz, F., Geel, B., 2023. NNP-ID: Non-Pollen Palynomorph Image Database as a research and educational platform. *Veget. Hist. Archaeobot.* 31, 323-328.
- Sowada, K., Ownby, M., Wodzińska, A., 2020. The petrography of import Levantine Combed vessels from early Old Kingdom Giza. *Levant* 52, 197-214.
- Stemler, A.B.L., 1980. Origins of plant domestication in the Sahara and the Nile Valley. In: Williams, M.A.J., Faure, H. (Eds.), *The Sahara and the Nile*. Balkema, Rotterdam, pp. 503-526.
- Stemler, A.B.L., Falk, R.H., 1984. Evidence of grains from the site of Wadi Kubbaniya (Upper Egypt). In: Krzyzaniak, L., Kobusiewicz, M. (Eds.), *Origin and Early Development of Food- Producing Cultures in North-Eastern Africa*. Poznan Archaeological Museum, Poznan, pp. 129-136.
- Strouhal, E., 1992. *Life in ancient Egypt*. Cambridge University Press, Cambridge.
- Tallet, P., 2015. Food in ancient Egypt. In: Wilkins, J., Nadeau, R. (Eds.), *A companion to food in the ancient world*. Wiley Blackwell, Hoboken, pp. 319-325.
- Tierney, J.E., Pausata, F.S.R., deMenocal, P.B., 2017. Rainfall regimes of the Green Sahara. *Sci. Adv.* 3, e1601503. DOI: 10.1126/sciadv.1601503
- Tweddle, J.C., Edwards, K.J., Fieller, N.R., 2005. Multivariate statistical and other approaches for the separation of cereal from wild Poaceae pollen using a large Holocene dataset. *Veg. Hist. Archaeobot.* 14, 15-30.
- Van de Bos, Valerie, R.N., Rees, A., Woods, L., 2020. Density separation in pollen preparation: How low can you go? *J. Paleolimnol.* 63, 225-234.
- Van Zeist, W., de Roller, G.J., 1993. Plant remains from Maadi, a predynastic site in lower Egypt. *Veget. Hist. Archaeobot.* 2, 1-14.
- Weiss, H., 2017. *Megadrought and collapse: from early agriculture to Angkor*. Oxford University Press, Oxford.
- Zhao, X., Liu, Y., Thomas, I., Salem, A., Wang, Y., et al., 2022. Herding then farming in the Nile Delta. *Commun. Earth Environ.* 3, 88. <https://doi.org/10.1038/s43247-022-00416-7>
- Zhao, X., Sheisha, H., Thomas, I., Salem, A., Sun, Q., et al., 2021. Climate-driven early agricultural origins and development in the Nile Delta, Egypt. *J. Archaeol. Sci.* 136, 105498. <https://doi.org/10.1016/j.jas.2021.105498>

Zhao, X., Thomas, I., Salem, A., Alassal, S.E., Liu, Y., et al., 2020. Holocene climate change and its influence on early agriculture in the Nile Delta, Egypt. *Palaeogeogr. Palaeoclimatol. Palaeoecol.* 547, 109702. <https://doi.org/10.1016/j.palaeo.2020.109702>

Figures

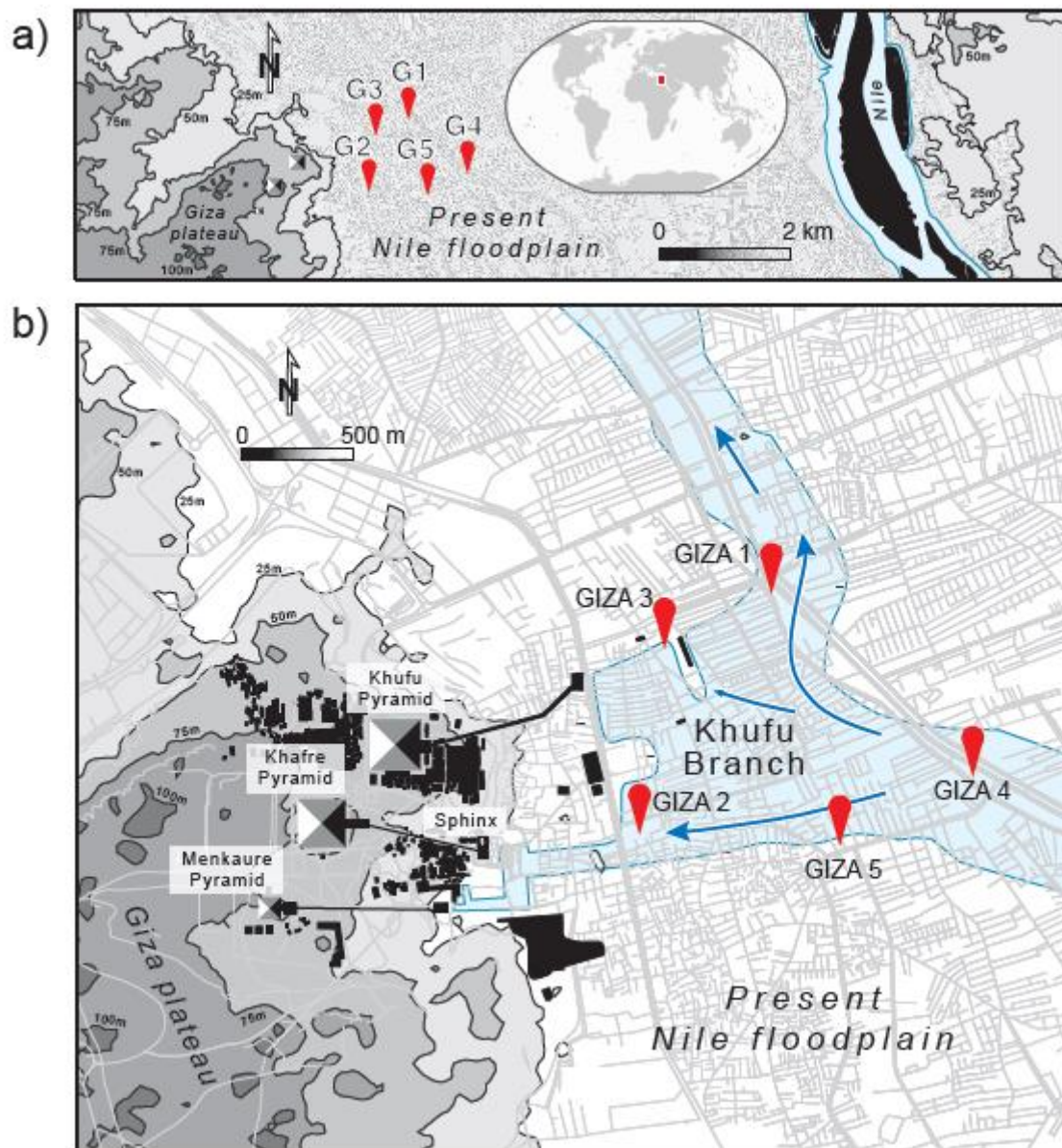


Figure 1. Map showing the cores G1 and G4 used to study the evolution of human behaviour and livelihoods at Giza. The two cores are located in the defunct Khufu branch of the Nile. (a) Map of the present Nile floodplain near the pyramids. (b) Map of the ancient floodplain with the Khufu branch highlighted in blue (Sheisha et al., 2022).

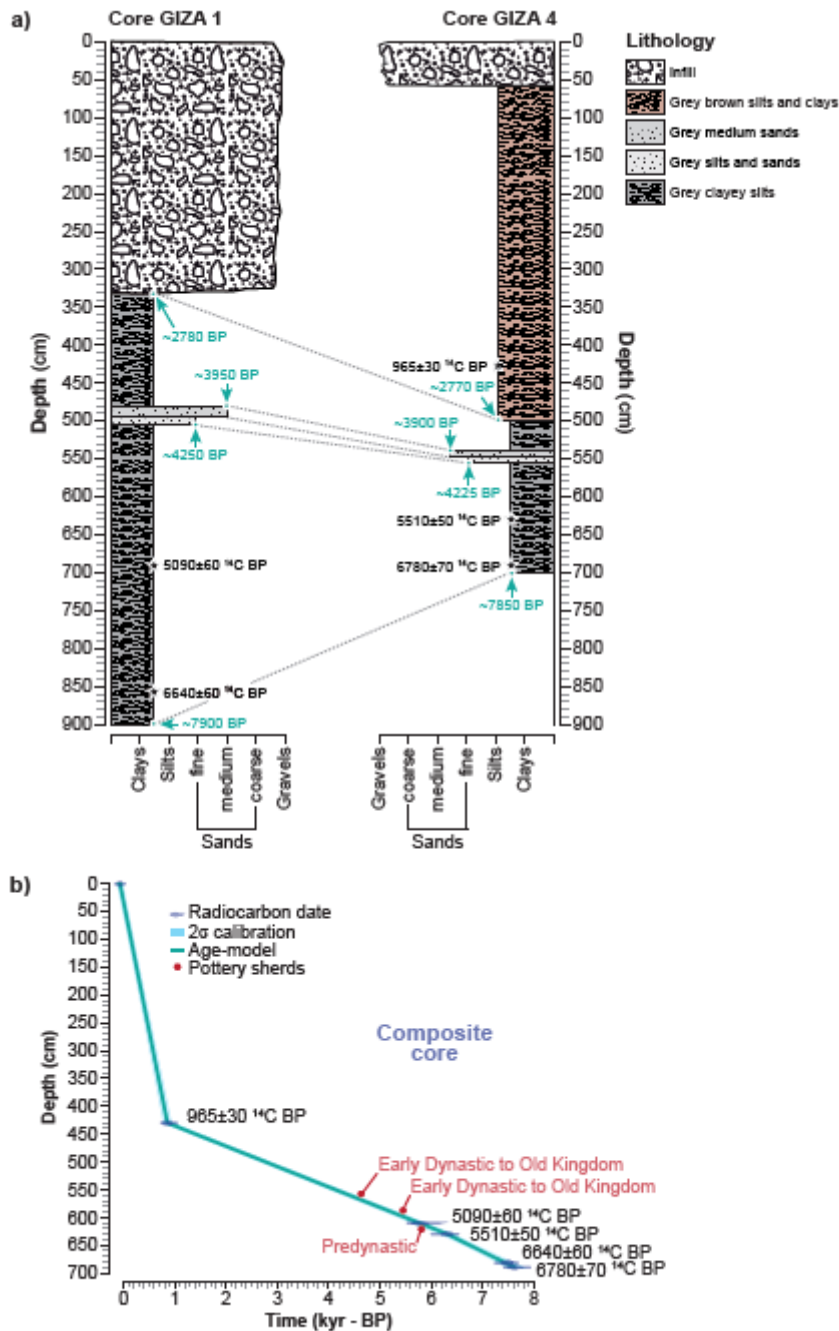


Figure 2. Lithology and radiocarbon dating of the core K-1 (G1 and G4). (a) The detailed lithofacies of the two cores are plotted against depth (cm). The radiocarbon ages are indicated by a black star. The green circles represent calculated ages. (b) Age-depth model for the core K-1. The age model was performed using Clam age-depth modelling on R software. The radiocarbon dates (^{14}C BP) are depicted as intercepts and 2-sigma calibrations (95% probability).

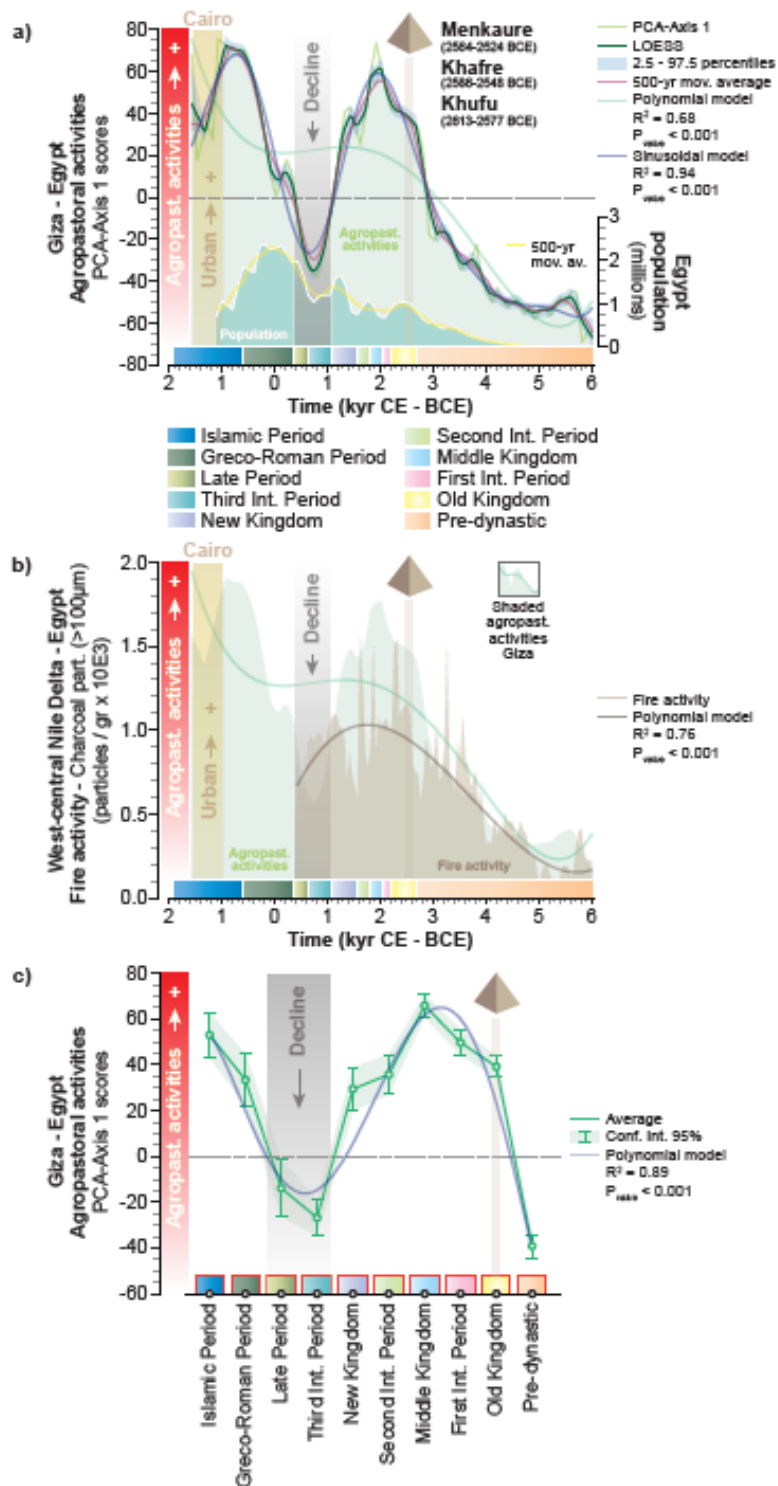


Figure 3. Agropastoral activities at Giza compared with the evolution of population in the Nile valley and human-induced fire in the delta. (a) Agropastoral activities are shown as a PCA-Axis 1 and a LOESS smoothing with the 2.5-97.5 percentiles. A 500-yr smoother (moving average), a polynomial regression and a sinusoidal model were added to describe the

long-term trends. The population dynamic in the Nile valley (Butzer, 1976) is displayed with a 500-yr moving average. **(b)** The human-induced fires in the delta (Zhao et al., 2022) are also shown with a polynomial regression. The agropastoral activities at Giza are indicated as shaded curve. **(c)** The PCA-Axis 1 scores are averaged per periods and shown with the associated confidence intervals and a polynomial regression.

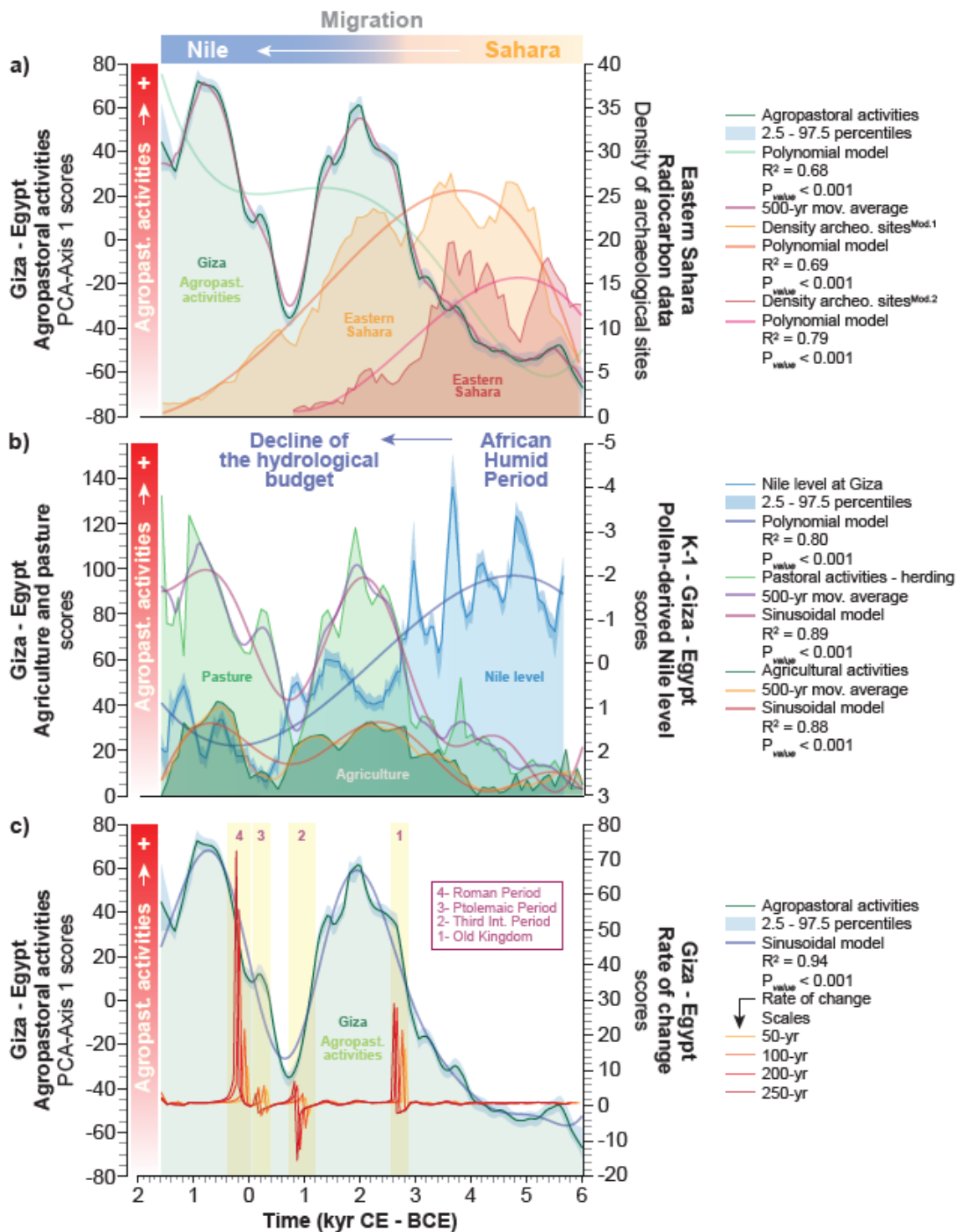


Figure 4. Agropastoral activities at Giza compared with the migrations out of Sahara and variations of the Nile's Khufu-branch level. (a) Agropastoral activities are shown as a LOESS smoothing with the 2.5-97.5 percentiles. A 500-yr moving average and a polynomial

regression were added to highlight the long-term trends. The Density of archaeological sites derived from two studies (Model 1 and Model 2; Kuper and Kröpelin, 2006; Manning and Timpson, 2014). A polynomial regression was added for each model. **(b)** Pasture and agriculture are shown as scores with a 500-yr moving average and a sinusoidal regression. The level of the Khufu branch is shown as a LOESS smoothing with the 2.5-97.5 percentiles (Sheisha et al., 2022). A polynomial regression was added. **(c)** Rate of changes in PCA-Axis 1 shown at different scales against with a backdrop of agropastoral activities (LOESS smoothing with the 2.5-97.5 percentiles and with a sinusoidal regression). The major changes are highlighted in yellow.

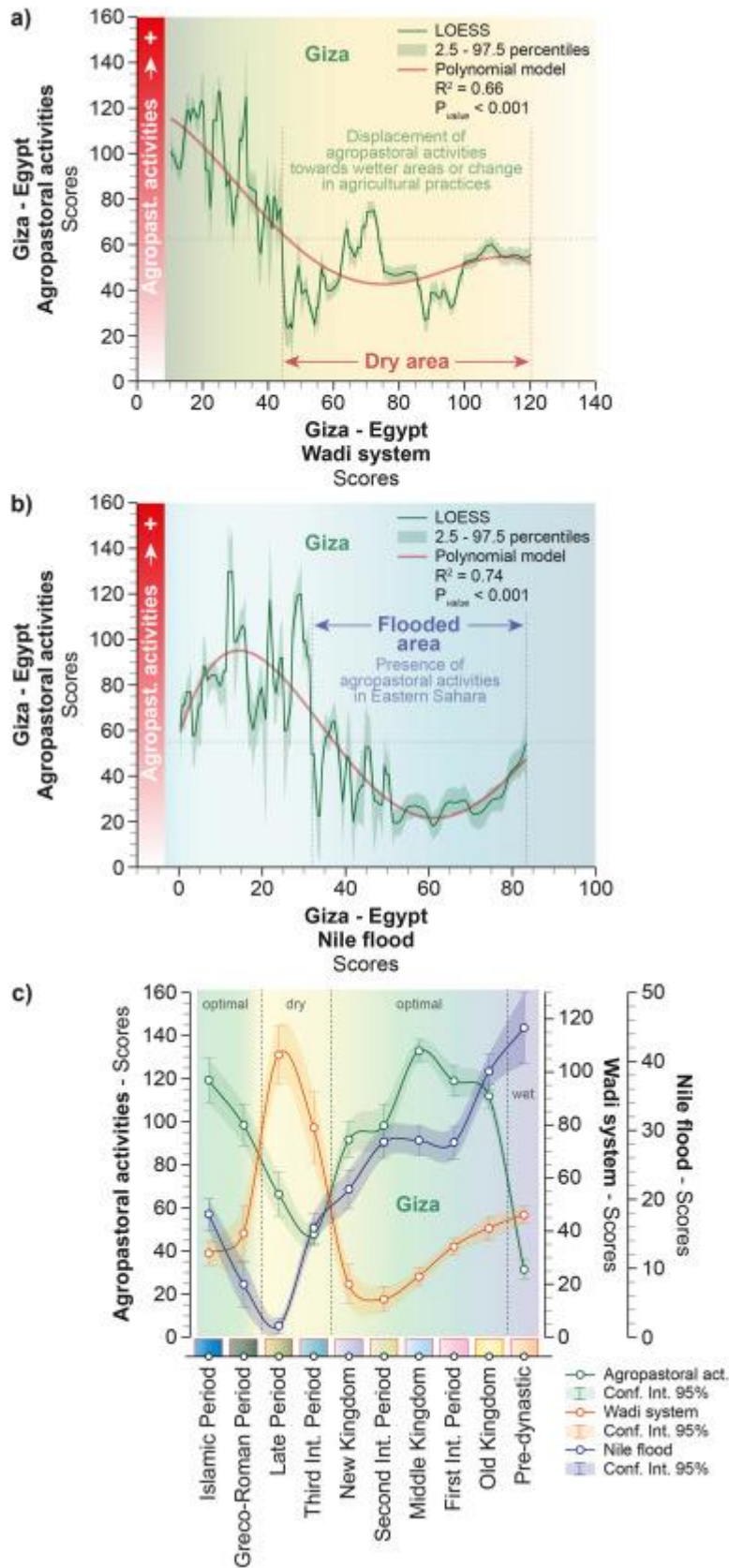


Figure 5. Distribution of agropastoral activities at Giza according to the wadi expansion and the severity of Nile floods. (a) Agropastoral activities plotted against the expansion of

the wadi at Giza. The data are shown as LOESS smoothing with the 2.5-97.5 percentiles. The long-term trend is highlighted by a polynomial regression. **(b)** Agropastoral activities plotted against the severity of Nile floods at Giza. The data are shown as LOESS smoothing with the 2.5-97.5 percentiles. The long-term trend is highlighted by a polynomial regression. **(c)** Agropastoral activities, Nile floods and expansion of the wadi system shown as average per periods with the associated confidence intervals (95% two-tailed confidence interval).

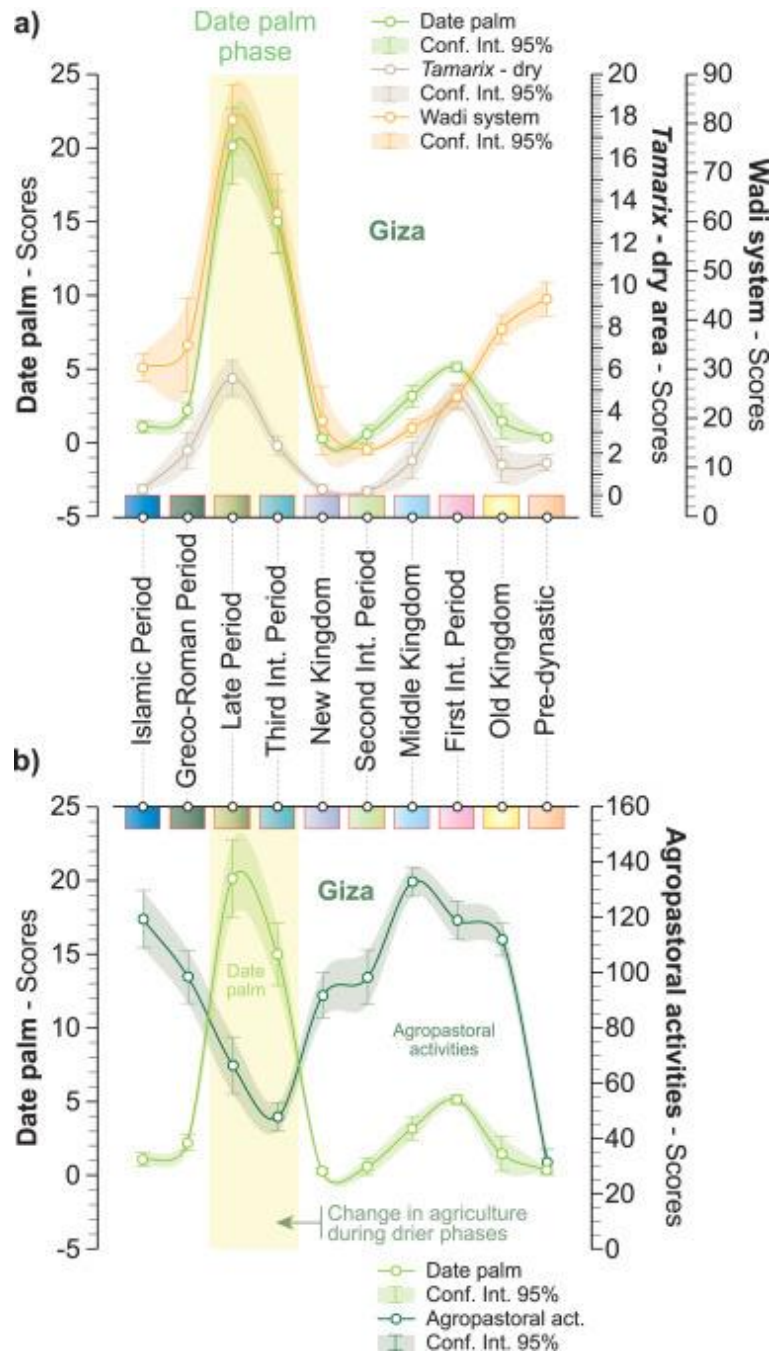


Figure 6. The date palm cultivation phase. (a) Evolution of date palm cultivation compared with the expansion of the wadi system and tamarisk. All data are shown as average per periods with the associated confidence intervals (95% two-tailed confidence interval). (b) Evolution of date palm cultivation compared with the dynamic of the traditional agropastoral activities. All data are shown as average per periods with the associated confidence intervals (95% two-tailed confidence interval). The yellow strip highlights the highest scores of date palm cultivation.