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## RESEARCH PAPER

# Lake Level Changes, Lake Edge Basins and the Palaeoenvironment of the Fayum North Shore, Egypt, during the Early to Mid-Holocene

Rebecca Phillipps\*, Simon Holdaway\*, Rebecca Ramsay\*, Joshua Emmitt\*, Willeke Wendrich† and Veerle Linseele‡

Fluctuations in the levels of Lake Qarun, Fayum, Egypt have long been recognized and are associated with Epipalaeolithic and Neolithic occupations dating to the early to mid-Holocene, some of which contain early evidence for the presence of southwest Asian domestic plants and animals. Here evidence for the extent and timing of these lake level changes is reassessed based on the analysis of a satellite derived digital surface model of the north shore of Lake Qarun. A more accurate topography for the region casts doubts on previously published lake level changes. The topography of a series of lake edge basins is assessed and used to make inferences about the nature of the early to mid-Holocene palaeoenvironment. This assessment in turn allows discussion of the significance of environmental change for shifts in the mid-Holocene palaeoeconomy documented in the Fayum.

**Keywords:** palaeoenvironment; lake levels; Fayum; Egypt

## Introduction

The Fayum is a natural depression, separated from the Nile Valley by a ridge known as the Nile-Fayum divide (Sandford & Arkell 1929). The north shore of this basin refers to the shoreline of Lake Qarun and is well known archaeologically because of work by Caton-Thompson and Gardner (1934) who studied deposits that are now known to date from the early to mid-Holocene. Their initial work showed the presence of domesticates both plants (wheat and barley) and animals (sheep, goat, cattle and pig) all of which originated from southwest Asia. Subsequently, the occurrence of these domesticates was found to be amongst the earliest in Egypt. Caton-Thompson and Gardner excavated two stratified sites, Kom K and Kom W and discovered the 'K Pits', a large number of basket lined, grain storage bins (**Figure 1**). Their work was followed up by a number of projects in the second half of the 20<sup>th</sup> century, which confirmed their findings and demonstrated the relatively late arrival of domesticates into Lower Egypt, well after they were domesticated in southwest Asia (Kozłowski & Ginter 1989; Wendorf & Schild 1976; Wenke, Long, & Buck 1988).

Floodwaters from the Nile Valley once entered the Fayum Basin at Hawara and caused fluctuations in the

level of Lake Qarun. At present the surface of the lake averages 44 m below sea level (bsl) but in the early Holocene the lake was considerably higher and therefore covered a much greater surface area than it does today. Fluctuations in lake levels were recognized by Caton-Thompson and Gardner (1934) and were incorporated in their assessment of cultural changes in the Fayum including the Neolithic and, as we discuss below, in the chronostratigraphic interpretations developed by subsequent 20<sup>th</sup> century researchers. Caton-Thompson and Gardner mapped the Fayum basin and recognized a series of depressions along the Fayum north shore that they termed basins designating these with a series of letters. Here we review what is known about the lake level fluctuations in relation to the topography of the Lake Qarun north shore and the basins they identified. We report on new data obtained from satellite imagery of the Fayum north shore used to construct a Digital Surface Model (DSM). With this model, the lake basins Caton-Thompson and Gardner identified can be shown to vary in extent and steepness. We discuss the significance of this variability for interpretations of the Fayum north shore palaeoenvironment and for the composition of archaeological deposits that are found adjacent to the basins.

## Lake Level Fluctuations and the Archaeology of the Fayum North Shore

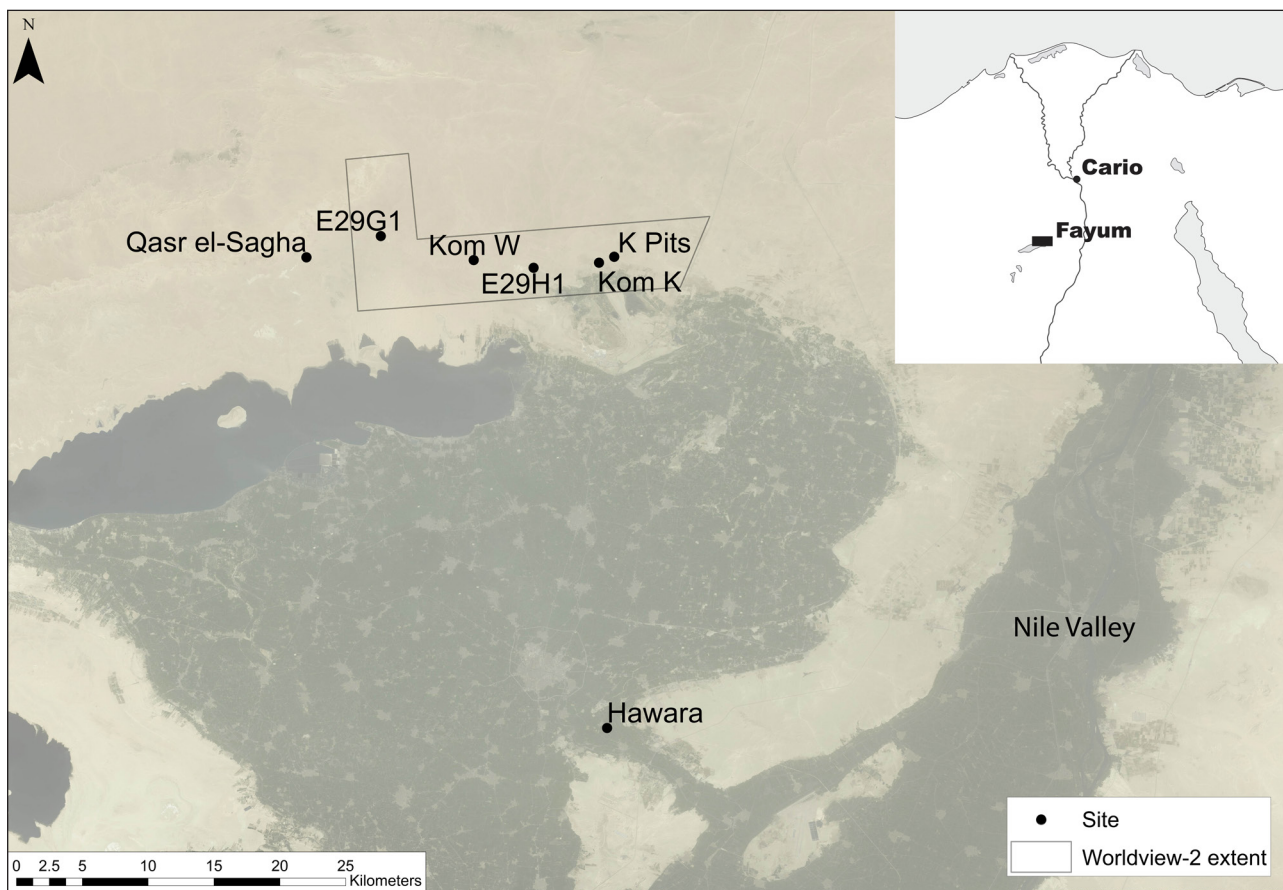
Caton-Thompson and Gardner (1929) were well aware that Lake Qarun was once a more substantial body of water and proposed a Pleistocene version of the lake with a

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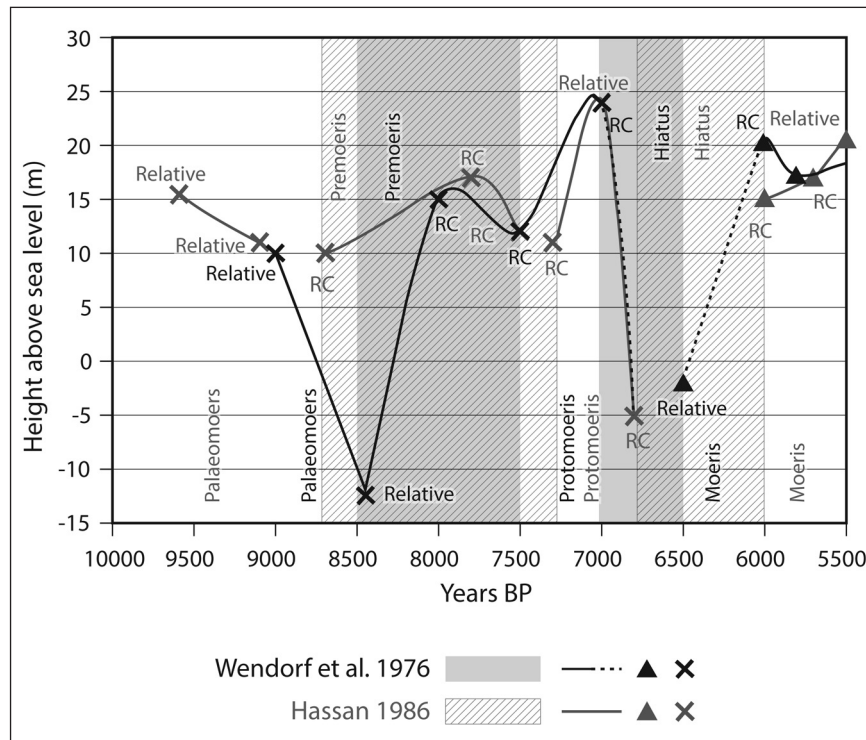
**Figure 1:** Fayum basin showing locations mentioned in text and the extent of the Worldview-2 DSM.

height of 40.3 m asl. They suggested that this lake receded and was replaced by a second lake rising to a maximum height 18.39 m asl, subsequently falling to 10.1 m asl during the Neolithic. This second lake then progressively fell with stages at 10–6 m asl, 4 m asl, and 2 m bsl. What they termed ‘Fayum A’ archaeological deposits, characterized by concave base projectile points and pottery thought to represent the Neolithic, were associated with the 10–6 m asl high lake stands. Settlements associated with the lower lake stages (4 m and 2 m bsl) were found with artefacts belonging to what was described as a Mesolithic group, ‘Fayum B’. Because Caton-Thompson and Gardner assumed that lake recession was a continuous process, their ‘Fayum B’ was interpreted as post-dating the higher ‘Fayum A’ Neolithic, a change that indicated a cultural ‘regression’ (Caton-Thompson & Gardner 1934, 2).

Wendorf and Schild (1976) disagreed with the interpretation of a gradually lowering Holocene lake, suggesting instead a series of four lake advances with associated lake retreats (**Figure 2**). These lake changes allowed them to dispense with a cultural regression and recognize Fayum B as a form of Epipalaeolithic industry. They dated changes in lake levels using radiocarbon determinations from hearths interpreted to have been located close to the palaeolake edges (Wendorf and Schild 1976). On the basis of the topographic locations of these hearths, the shoreline locations for the palaeolakes were proposed with different locations linked together using a series of chronostratigraphic correlations. Hassan (1986), working on

the southwestern shoreline of Lake Qarun built upon this work and while some modifications were made to the lake sequence proposed by Wendorf and Schild, these involved the use of the same chronostratigraphic techniques. His work was in turn modified by Kozłowski and Ginter (1993) who reported on chronostratigraphic sequences in the region of Qasr el-Sagha. **Figure 2** summarizes lake changes proposed in the Wendorf and Schild (1976) and Hassan (1986) studies and indicates where lake advances and retreats were thought to be tied to radiocarbon determinations, largely obtained from hearths.

Those working in the Fayum Basin all recognized that palaeoshorelines, lake sediment, and shell deposits indicated how the modern day Lake Qarun was once a more substantial body of water. What was not known directly, however, was the chronology of any lake advances and retreats that occurred during the early to mid-Holocene. The attempts made to develop such a chronology were based on age determinations largely from datable materials in archaeological deposits rather than materials derived from the shoreline deposits themselves. In doing so, the assumption was made that the archaeological materials found on lake edge deposits reflected lake edge occupation. Therefore, age estimates for these materials could be used to provide a chronology for the deposition of the lake edge sediments. Following this assumption, variations in the age and locations of hearths dating from the early to mid-Holocene seemed to indicate a sequence of lake advances and retreats, the variations of which are



**Figure 2:** Early to Mid-Holocene models of lake level fluctuations (m asl) for Lake Qarun. Lake level changes from Wendorf and Schild (1976) and Hassan (1986). RC indicates a date from a radiocarbon determination. Relative indicates an age estimated from a stratified sample. Modified from Phillipps 2013, figure 5.7.

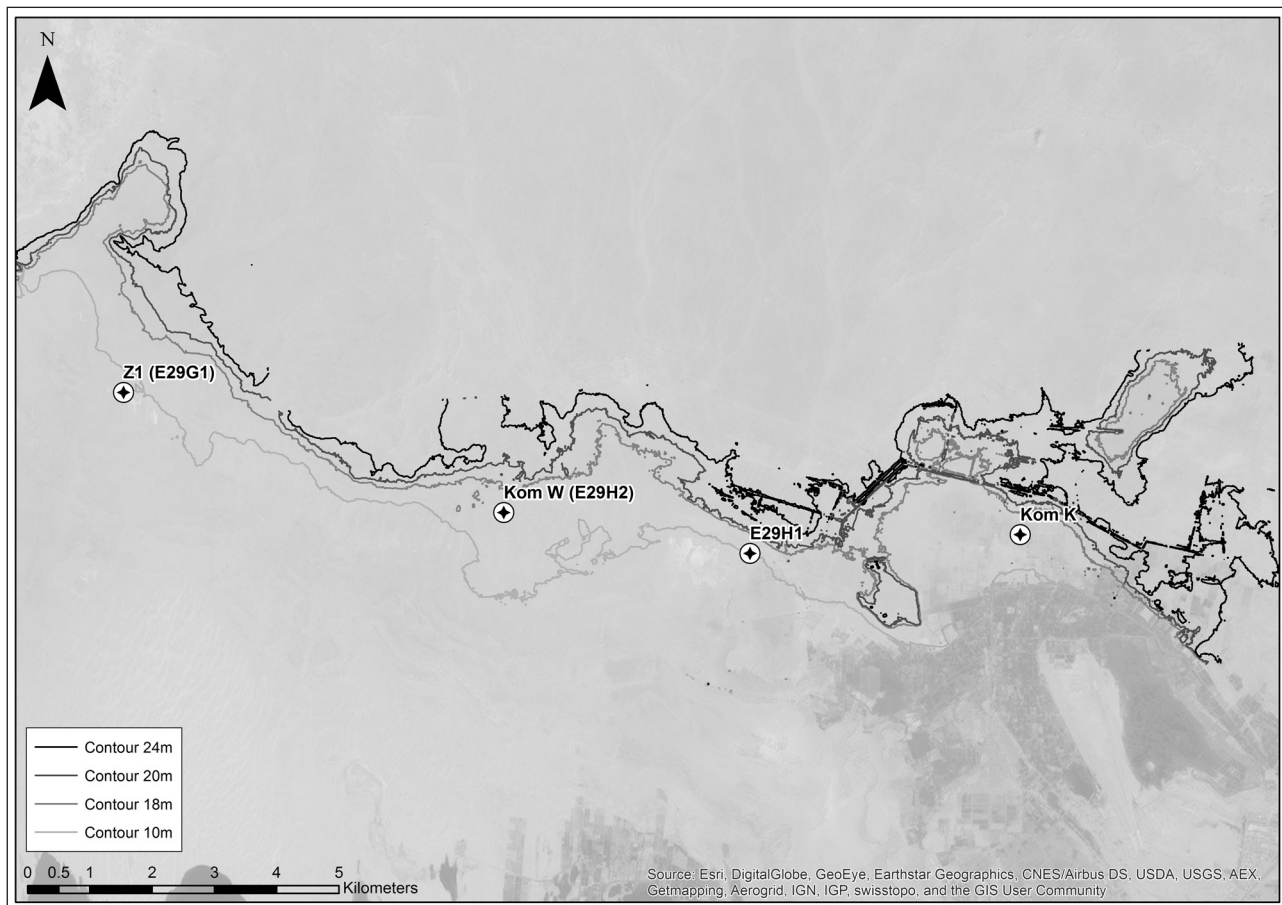
summarized in **Figure 2**. The heights above sea level (asl) of the sediments on which the datable archaeological material rested provided a means of establishing a chronostratigraphy that could be traced across both the northern and southwestern regions of the Fayum Basin (Hassan 1986; Kozłowski & Ginter 1989; Wenke, Long, & Buck 1988). This chronostratigraphy in turn suggested an early Epipalaeolithic occupation of the Fayum (the equivalent of Fayum B) replaced by a later, and separate Neolithic, the equivalent of Fayum A. Both these occupations were closely connected to different periods of lake advances and retreats, and were separated by a pronounced hiatus of an estimated 500 years. However, as we report here, there are now reasons to question the basis on which these reconstructions were made.

Lakes were certainly attractive to people in the past but how people interacted with these lakes varied based on a number of factors, such as lake edge morphology, cultural preferences, and particular use of lake resources. People may have lived immediately adjacent to water bodies but they also might have lived some distance away while still utilizing the resources that these water bodies provided. How far people lived away from Lake Qarun is of course critical for the construction of a chronostratigraphy of lake changes because the published chronologies for changing lake levels require that the archaeological ages obtained from materials resting on the lake edge sediments relate to the times when these sediments were deposited. If for instance, people lived away from the lake edge rather than directly adjacent to it, then a direct chronological relationship between the sediments and the archaeological materials

would not exist. Unfortunately the need for this assumption undermines the proposed chronostratigraphies illustrated in **Figure 2** and indeed calls into question the existence of multiple lake advances and retreats at the times that they are proposed.

There is moreover a second problem with the interpretations summarized in **Figure 2**. The chronostratigraphic correlations on which lake level rises and falls were based required that sediments from different locations in the northern and southern parts of the Fayum Basin could be related through their height above sea-level. Obtaining exact locations and associated heights of stratigraphic sections was of course difficult in the past. With GPS technology combined with remotely obtained DSM discussed below, it is now possible to be more certain about the location, and especially the elevation, of points on the surface of the earth. Here we report new satellite derived data sets combined with GPS derived locations for archaeological materials that show errors in absolute height estimates for the Fayum stratigraphic sections that were recorded by previous researchers. For example, at E29G1 and E29H1 (**Figure 3**), height estimates in the published contour maps are different by several meters compared to those that were obtained from a satellite derived DSM. Any errors of this type are cumulative in the sense that an error introduced in one study will lead to potentially false chronostratigraphic correlations in later studies. Thus, errors in the heights attributed to E29G1 that were accepted as correct by both Hassan (1986) and Kozłowski and Ginter (1993) mean that the chronostratigraphic correlations that they propose must be treated with caution.





**Figure 3:** Fayum north shore 10 m, 18 m, 20 m, and 24 m contours from DSM 1 m data. Proposed lake advances above 10 m submerge the four sites indicated.

With an accurate satellite derived DSM as well as the results of extensive surveys based on GPS and total station mapping that document the extent and state of preservation of the archaeological record across the Fayum north shore, we are now able to reassess the nature of the early to mid-Holocene palaeoenvironment. Of particular interest is the topographic relationship between archaeological materials and the series of lake edge depressions that Caton-Thompson and Gardner (1934) originally identified as 'basins'. Here we consider the relationship between these basins, palaeolake levels, and evidence for wadi systems that suggest water flow into the basins in relationship to the distribution and content of north shore archaeological deposits. We also consider the significance of these data sets for deriving inferences about the nature of the palaeoenvironment of the Fayum north shore.

### Early to Mid-Holocene Palaeoenvironment of Northeast Africa

Variation in the level of Lake Qarun during the early to mid-Holocene needs to be understood in relation to a number of larger scale environmental processes operating in northeast Africa (Phillipps et al. 2012). Occupation and abandonment of locations in the eastern Sahara is consistent with the northward shifts of the Inter Tropical Convergence Zone (ITCZ) (Hassan et al. 2001; Kindermann 2004; Kindermann et al. 2006; Kuper & Kröpelin 2006; Marshall & Hildebrand 2002; McDonald 2009; Wendorf &

Schild 2001). However, the northern limit of the ITCZ did not reach the Fayum, so any periodicity in the occupation of the Fayum is unlikely to relate directly to the ITCZ but needs instead to be thought of in relation to the local outcome of this and related regional environmental processes (Haynes 2001; Kuper & Kröpelin 2006; McCorriston 2006). Although variation in the northward movement of the ITCZ certainly had an impact on Nile River flow, variation in Nile flow levels are now known to be more complex than once thought. In an older study, for example, Hassan (1984: 58) suggested that a separation between Epipalaeolithic and the Neolithic occupations in the Fayum related to the sudden decline in the level of Lake Qarun as a result of reduced Nile River flows. The Fayum Neolithic was correlated with what was thought to be a period of increased Nile flow and therefore higher lake levels (Hassan 1997: figure 1). However, recent work suggests an increase in White and Blue Nile flow at approximately 6.56 – 6.25 ka, about the time that the Fayum appears to have been abandoned (Williams et al. 2010). If increased Nile flow did indeed lead to increased lake levels, then this may be correlated with abandonment rather than renewed occupation. Williams (2009: 11) provides one possible explanation for this abandonment, proposing that it was times of lower rather than higher Nile flow and Nile incision that were conducive to agriculture on the Nile floodplain since this allowed swampy ground to drain. Potentially, a similar argument may apply to the Lake Qarun north shore,

if indeed this environment was similar to the Nile floodplain. Determining the true relationship between the Lake Qarun shoreline and evidence of human occupation is obviously crucial if links to fluctuations in Nile levels and associated shoreline environments are to be made.

In addition to shifts in the ITCZ, there is evidence for a southward movement of Mediterranean winter rains at times during the early to mid-Holocene (Arz et al. 2003; Bryson 1992; Hassan et al. 2001; Kindermann et al. 2006; Phillipps et al. 2012). Palaeoclimatic evidence indicates more winter rainfall from the eastern Mediterranean may have fallen in the Fayum than it does today. Modern day rainfall in the region occurs with depressions and cold frontal troughs. Changes in Red Sea salinity in the early to mid-Holocene indicate a southwards shift of Mediterranean winter cyclonic rainfall while lower sea surface temperatures in the northern Red Sea and the eastern Mediterranean during the period indicate the inflow of cold continental air masses during winter (Arz et al. 2003: 119). The presence of these air masses during the mid-Holocene likely resulted in increased winter precipitation falling further south than it now does (Phillipps et al. 2012). If this occurred, then water flow may have occurred via wadi systems like those north of the lake basins unrelated to changes in Nile River flow.

Whatever the source of water, changes in water availability likely had an impact on local flora and associated local fauna. Hassan (1986: 497) discussed the potential issues that the presence of reed thickets along lake edges might impose for those intent on cultivation. Others have discussed the effect of lower sediment loads flowing into Lake Qarun with the Nile flood and the amount of the lake edge that was actually covered by floodwaters (Bard 2008; Wenke 2009; Wenke, Long, & Buck 1988). Any increase in Nile flood water, due to increases in summer precipitation in Ethiopia at around 6.1 ka, might have decreased sediment loads in the Nile River. Williams (2009) uses this to suggest that from this period, conditions may not have been optimal for Nile flood based agriculture. The nature of the connection between the Nile and Lake Qarun must also be considered, not only in relation to sediment deposition, but to salinity levels of the lake itself. As discussed below, while palaeoenvironmental proxies are not always available, a great deal can be learned by considering the topography of the Fayum north shore, particularly the series of basins that Caton-Thompson and Gardner originally identified.

### Methods: Digital Surface Model Generation

As part of a recent project designed to study the landscape archaeology of the Fayum north shore (Holdaway and Wendrich in press; Holdaway et al. in press), a Worldview-2 stereo satellite imagery pair (dated 17 May 2012) was obtained for a 142 km<sup>2</sup> area of the Fayum north shore that covered the area for which we had a concession to work. Initial processing of these images produced a DSM based on a 1 m pixel size with a vertical accuracy of 4 m (Figure 1). The vertical accuracy was improved by comparing the DSM derived heights with height values from 676 surveyed points obtained with a total station located

with a Trimble Pathfinder ProXRT differential GPS (DGPS) with OmniSTAR correction (0.10 m horizontal accuracy, 0.15 m vertical accuracy). An average difference of 2.886 m was indicated between equivalent points and the DSM was then lowered 2.88 m to compensate. The resulting corrected DSM was then used for height control in the orthorectification of the most vertical of each Worldview stereo pair. The pan image was used to pansharp the multispectral image, providing a 0.5 m resolution, natural color image, and allowing the production of high resolution georectified contour maps of our Fayum north shore study region.

The Worldview stereopair was not large enough to cover the entire area of interest for this study. To place the Worldview stereopair in its wider regional context, an Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) of the whole Fayum region was also obtained and used to visualize, and subsequently digitize, an accurate surface model for the reconstruction of potential high lake stands, basin area, and topography at various levels and scales based on elevation above sea level (see below). The ASTER GDEM has a worldwide coverage so the entire Fayum region could be analysed.

Although areas of the Fayum north shore are today under cultivation, and therefore have been topographically modified, the areas where the early to mid-Holocene archaeological record are concentrated are by and large in good condition and separated from modern development (although this situation is rapidly changing). Within the area of archaeological interest, deflation has modified some regions while in others aeolian sand movement has changed the local surface topography. However, across the area covered by the Worldview stereo pair these regions are easy to isolate and exclude, as are any areas subject to modern development. With these caveats, it is reasonable to assume that the derived DSM provides a reasonably accurate representation of the Holocene topographic surface.

Figure 3 highlights the 10 m, 18 m, 20 m, and 24 m contours based on the modified DSM derived, 1 m Worldview contours for the Fayum north shore. The locations of the stratified sites identified by Caton-Thompson and Gardner (1934), Kom W and Kom K, and the surface sites identified by Wendorf and Schild (1976), E29H1, E29G1, are plotted together with lake high stand heights proposed in previous studies based on chronostratigraphic comparisons. Lake advances between 18 m and 24 m submerge all of these sites and the areas with surface archaeological deposits that surround them. Even a lake advance to the 18 m contour means that the majority of the areas that we have identified with surface archaeological deposits would be beneath the lake waters (Holdaway & Wendrich in press).

In addition to examining past lake levels, the high resolution DSM combined with a larger coverage ASTER GDEM allows examination of local topographic variability in the Fayum Basin. As noted above, in their original study, Caton-Thompson and Gardner (1934) identified a series of basins along Fayum north shore. They suggested

that during the Neolithic one of these basins, Z Basin, formed an inlet from the high stand Lake Qarun which they thought might have attracted occupation. A falling lake level then caused a series of basins, Z, X, K, L, and U (a basin that they left unnamed and the U designation is ours) to become lagoons, which they thought also attracted occupation. Caton-Thompson and Gardner (1934) noted the presence of wadis that they suggested directed water flow into the lake edge basins. These wadis were also remarked upon by Kozłowski and Ginter (1993: 333) who suggested that increased rainfall might have fed wadi activity during periods of lake recession.

As long as a permanent connection existed between Lake Qarun and the Nile, the intensity of Nile discharge likely had some effect on the level of Lake Qarun. However, local topographic variability along the lake edge together with the quantity of discharge controlled the impact of

any changes in lake level. Different amounts of land surface were subject to inundation and exposure depending on the steepness of the topography. Such changes likely had an effect on local vegetation growth, and therefore the animal habitats that the basins supported.

The six basins (Z, X, L, K, N, and U) identified by Caton-Thompson and Gardner (1934) can be seen in the satellite imagery (Figure 4). The area of each basin as defined by Caton-Thompson and Gardner's original boundaries was confirmed by comparing these with the contemporary satellite imagery ASTER GDEM in addition to the Worldview-2 stereo imagery derived DSM. Areas were identified where recent development disturbed the topographic surface. With these areas excluded, elevation values were extracted for each basin, based on a mask of each basin area derived from Caton-Thompson and Gardner's original work. These points were used to create a raster surface to a resolution

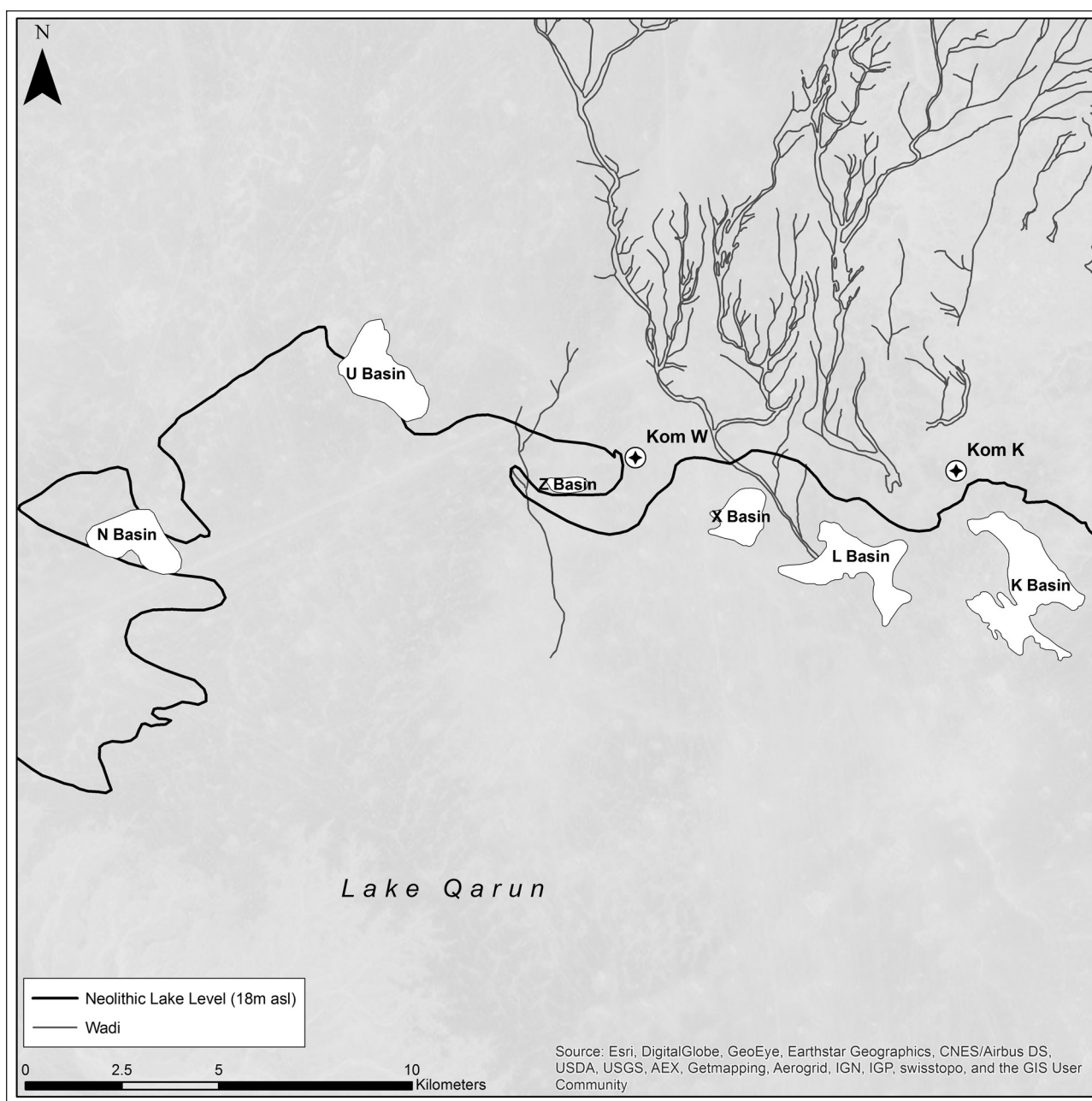


Figure 4: The wadis, basins and Neolithic lake edge (18 m asl) identified by Caton-Thompson and Gardner (1934).



of 30 m, with values based on elevation. A slope function command in ESRI ArcGIS was used to derive slope for each cell, measuring the maximum change in elevation between cells, and displayed as change in slope between 0° and 90°. The slope values were reclassified into a nine-unit hillslope model, based on slope angle following Parsons (1988: 28). It was reasoned that lower slopes would receive more sediment deposition, while steeper slopes would often times be more prone to erosion. Thus, changes in slope allow inferences to be made about local palaeoenvironment. The surface areas of each basin were calculated based on Caton-Thompson and Gardner's basin outlines.

**Results: Topographic Analysis**

Results indicate that K Basin is the largest (6.06 km<sup>2</sup>), followed by L basin (4.51 km<sup>2</sup>), U Basin (3.13 km<sup>2</sup>), X Basin (2.46 km<sup>2</sup>), N Basin (2.45 km<sup>2</sup>), and Z Basin (1.10 km<sup>2</sup>) (Table 1). Unfortunately, K Basin shows modern disturbance to the basin edges and is therefore unlikely to be representative of past slope so was not further investigated. Comparisons between the remaining basins suggest Z Basin (mean change of slope 65.07°) has the steepest gradient while X Basin (mean change of slope 16.99°) is the shallowest. The slope reclassification (Figure 5) shows the presence of only two classes, 1 and 2, in every basin except Z Basin, which contains five different classes (1–5).

In 1939, Ball suggested that Lake Qarun rose and fell between 2.5 m and 4.0 m annually during the Nile flood. Using recorded mid-Holocene archaeological remains at the sites investigated by Caton-Thompson and Gardner (1934) as well as Wendorf and Schild (1976) as an estimate of the absolute maximum lake level height, Ball's (1939) suggestion of lake level change can be used to examine the connectedness of the basins to the lake during low and high lake levels. The reconstructed high and low lake stands show that Z Basin and U Basin are the only two basins that remain connected to the main lake, if the lake

Basin	Degrees of slope change
Z	65.07
N	32.36
U	29.37
K	19.48
L	18.27
X	16.99

**Table 1:** Slope change calculations for the north shore basins identified by Caton-Thompson and Gardner (1934).

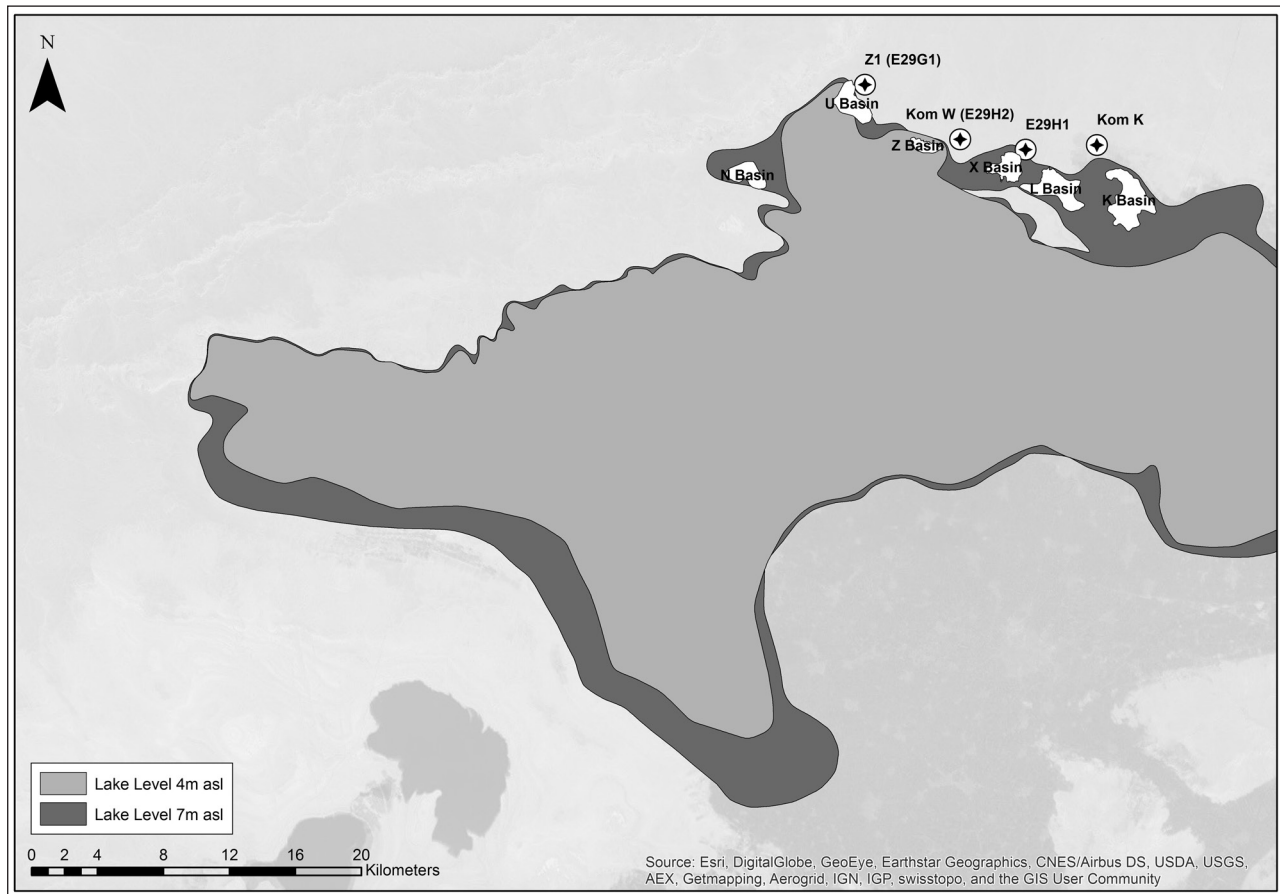
were to retreat 3 m during periods of lowered lake level (Figure 6). During high lake stands, all the basins were potentially connected to the lake. Based on this change in lake level elevation, summed across all the basins, approximately 235.7 km<sup>2</sup> of land surface would be alternatively inundated and exposed, if the lake level changed by 3 m. The significance of this reconstruction is not so much to accept the veracity of Ball's (1939) estimate of change in lake level due to fluctuations in Nile River inundation but rather to understand the impact a change in lake level of around this magnitude would have on the lake edge basins. Given the slope of each basin, it is likely that Basins X, L, K, and N could receive sediment if it was available as part of lake-fall, but U Basin, and especially Z Basin would be more prone to erosion due to steepness of the slope of these basins.

Detailed analysis describing the relationship between archaeological material and sediment for X basin is reported by Koopman et al. (2016) and suggests processes of erosion and deposition occurred throughout the Holocene. Future dating of sediments may be useful for establishing correlations with palaeoclimatic events. In addition to any sediment deposition and erosion, these results have implications for the types of vegetation and



**Figure 5:** Reclassification of basin slope values based on the Parsons (1988) nine-unit model (see text for details).





**Figure 6:** North shore Neolithic lake basin exposure and variability in this exposure associated with likely Nile inundation.

animal habitats that may have existed within the basins. Given the large shallow, and possibly unconnected nature of the eastern basins (K, L, X Basins), some fish species may not have survived in these environments during particular times depending on lake levels. Clariid catfish (Clariidae) and tilapia (Tilapiini) are shallow water fish that are adapted to living in deoxygenated environments (Brewer 1987: 461; Van Neer 2004) and so might be expected to have lived in the shallow eastern basins, provided there was a connection with the Nile at some point to allow the species to move into the basins. In contrast, the steepness and possibly higher energy environment of Z Basin may have provided a more suitable environment for species such as Nile Perch (*Lates niloticus*) (Brewer 1991: 291; Van Neer 2004). Although we lack direct evidence for the nature of the vegetation that characterized the different basins, hydrological changes may also have led to shifts in the communities that existed adjacent to these basins, particularly those near the shallower basins to the east. People in the past likely reacted to these changes as a consequence of shifts in the range of economically useful species that were present and in the varying potential that basin edge environments provided them for the cultivation of domestic plants and animals.

## Discussion

While access to modern georectified data sets indicates that the chronostratigraphic correlations used in previous studies must now be viewed with caution, the same data

sets indicate that the north shore lake edge topography is more variable than indicated in older studies. The lake edge basins that Caton-Thompson and Gardner (1934) identified are variable in their size and steepness, and this combined with the topography of the basin in general demonstrates how relatively small changes in lake level rise and fall could have led to the inundation and exposure of substantial areas. It is important to consider the implications of these data for interpretations of Fayum palaeoenvironment and the first use of domestic plants and animals.

The relatively late appearance of domestic species in Lower Egypt continues to interest archaeologists with a variety of environmental and cultural explanations invoked (summarized in Linseele et al. 2014). The majority of these explanations are based on the assumption that domestic species once available would always be considered more desirable than wild species. However, their uptake in North African appears to be patchy and wild species continue to dominate many faunal assemblages. A better approach to the assumption of desirability might therefore be to ask what conditions favoured the use of wild resources above the use of domestic species for a relatively long period.

Recent assessment of faunal material from the Fayum demonstrates the significance of fish above other species for all early to mid-Holocene occupations (Linseele et al. 2014). Wild ungulates are present in the earliest faunal deposits associated with radiocarbon determinations

from hearths dated to the earliest Holocene but are best interpreted as an addition to, and never a replacement for, fish exploitation. The same may be said for domestic sheep, goat, cattle, and pigs. When these species are found, they appear to supplement rather than replace fish that continued as the major economic resource until the Fayum was abandoned around 6 ka BP.

Domestic crops were also added to the Fayum economic resource base evidenced most famously by the K Pits from which wheat, barley, and flax seeds were found but also in hearth deposits from Kom K and Kom W. To what degree domestic plant species either supplemented or replaced wild plant resources cannot be known but based on the evidence we have, domestic grain use was not extensive. As noted, domestic species both plant and animal were supplements to rather than replacements for fish exploitation (Holdaway & Wendrich in press).

These observations need to be considered when interpreting the nature of human interactions with the Fayum palaeoenvironment. In the past, a great deal of weight was placed on inferences concerning changing lake levels in relation to the exposure of land suitable for cultivation. As discussed above, Hassan (1984, 1997) correlated proposed periods of lake recession and advance, with abandonment of the Fayum before reoccupation during the Neolithic. As an alternative, we suggested in a previous study (Phillipps et al. 2012), a link between periods in the Fayum when moister conditions prevailed, and what Williams (2009: 11) calls 'geological opportunism', a term introduced by Claudio Vita-Finzi (1978), used in this case to suggest that land was not sought out for cultivation until it was physically possible to do so. If so, then one interpretation of the presence of domestic plants and animals in the Fayum would be that these were introduced only when a suitable habitat for cultivation became available. The period when domestic species are first evidenced in the Fayum, in the mid 6<sup>th</sup> millennium BC (Linseele et al. 2016) roughly correlates with the Mediterranean dispersal of southwest Asian plant and animal domesticates from Turkey into south eastern Europe (Weninger et al. 2014; Zeder 2008), possibly indicating that the northern Egyptian environmental conditions enabled the use of the southwest Asian domesticated species at the time when people were moving around the Mediterranean Basin. However, while domestic species and associated technologies were exported, the introduction of southwest Asian domesticates around the Mediterranean Basin, including Greece, Cyprus, Italy, Spain and Portugal also indicates local variability in environmental interaction by a range of Neolithic colonists (Barich 2014; Finlayson 2004; Gkiastira et al. 2003; Lindstädtler et al. 2012; Perles 2001; Runnels 2003; Zeder 2008) and it is possible that something similar was occurring in Egypt.

The results of the analysis of Fayum basin topography presented above suggest that a much greater surface would be exposed in the eastern basins (X, L, and K Basin) compared to the western basins (Z and U Basin). If any early agriculture in the Fayum was indeed dependent on an annually receding lake level and exposure of irrigated land surface, a gentle slope gradient along some of the eastern basins would ensure sufficient annual exposure

of moist sediment. These basins might also be expected to retain sediments deposited during periods of inundation. During any periods of lower Nile flow, rainfall feeding the eastern basins through the wadis may have supplemented the water supply. If the lake did not inundate, or did not inundate to the degree suggested by Ball (1939), then rainfall may have been the only source of fresh water for the eastern basins during low lake stands.

However, the topographic analysis also indicates the potential impact lake level changes might have had on the lake basin ecosystems, especially in terms of the fish species that the faunal analyses indicate were of prime economic importance for people who occupied the Fayum throughout the early to mid-Holocene. Most fish found in the Fayum are from shallow waters, especially represented by clariid catfish (Clariidae) and tilapia (Tilapiini) but including fish from the Barbel family (Cyprinidae). Other species however are typical of well-oxygenated water, Bagrid catfish (*Bagrus* sp.), *Synodontis* catfish (*Synodontis* sp.), and Nile perch (*Lates niloticus*). The presence of mullet (Mugilidae) suggests a connection between the main lake and the Nile existed. In addition, these species suggest people had access to shallow near lake edge waters as well as deeper areas (Linseele et al. 2014).

Tilapia and clariid catfish are represented at Kom K by large, sexually mature specimens, with average standard lengths of about 30 cm and 60 cm respectively and were therefore likely captured when spawning in shallow waters, whether seasonally or otherwise (Linseele et al. 2014). Because the eastern basins were shallow and lacked steep shorelines, they may represent areas where this occurred, as they may only have received water from the lake during periods when the Nile flooded. At other times, they may have been rain fed via wadi systems. Brewer (1989) analysed growth rings on the pectoral spines of clariid catfish and correlated growth phases in these with periods of high temperatures. The conclusion from this study, that fishing was mainly practiced in May-June (i.e. at times with temperatures similar to those of modern Egypt's late spring or early summer), is compatible with the hypothesis that fishing happened mainly in the late summer months based on the predominance of adult spawning fish (Linseele et al. 2014) in the shallow water micro-environments provided by the eastern basins. What is interesting to consider is the impact on fishing any shift in the level on inundation may have had. As the reconstructions based on Ball's (1939) estimates indicate, relatively minor changes in the height of lake level inundation would have a dramatic effect on the area of land exposed and for the eastern Basins, the timing, degree, and even existence of direct contact with Lake Qarun. These types of changes may have had an impact on fish populations.

As noted, geological opportunism may account for the presence of domestic species in the Fayum but it is also possible that the use of domesticates was a response to environmental changes and their impact on the supply of fish. This of course, is simply another type of opportunism. The Fayum was apparently abandoned quite suddenly ca. 6.2–6 ka (Wenke 2009). One interpretation of this abandonment is that southwest Asian domestic species

could be used in the Fayum only under certain conditions. Marshall and Hildebrand (2002: 122) suggest that the southwest Asian domesticates were confined to the Nile Valley because they were winter crops, and thus dependent on the availability of water during November until April. If so, then the presence of winter rains in the northern Nile Valley were crucial to the success of the southwest Asian domestic grains, based on a winter rain growth cycle, and a collapse in use of these grains would have ensued if the winter rains retreated due to changes in the flow of cold air into the eastern Mediterranean discussed above.

However, an alternative explanation is that changes in the local hydrology connected with shifts in Nile River flow and the presence of winter rains changed the local environment of the shallow lake edge basins thus affecting the environments suitable for some of the fish species, particularly clariid catfish that were spawning. We know from the topographic analysis that relatively small changes in lake inundation might have dramatic effects particularly on the shallow basins. Thus, leading up to the period when the Fayum was abandoned, local environment conditions may have been quite variable dependent on shifts in Nile River levels following Williams et al. (2010) and changes in winter rainfall as detailed in Phillipps et al. (2012). Seen from this perspective, the incorporation of domestic species into Fayum economic practices becomes less a question of inevitability and more one of a response to increased environmental variability. Whatever the changes introduced, they did not last post 6 ka BP when the northern Fayum was mostly abandoned and not reoccupied until Greco-Roman times.

Sometime after the Fayum north shore was abandoned cultivation of domesticated cereal species led to the development of the *décrue* system of Nile flood manipulation in the Nile Valley, the economic foundation for Dynastic civilization (Butzer 1976: 20). The assumption is sometimes made that that this system evolved directly out of the Neolithic evidenced at places like the Fayum as well as sites in the Delta (e.g. Bard 2008). However, there is no necessity that one system begat the other. As summarized above, cultivation in the Fayum to the degree that it existed, likely relied on winter rains rather than the summer inundation. At least based on the Fayum evidence, the summer resource that we know was seasonally exploited was fish. If we can overcome our own biases that see domestic species as inevitably better than wild resources, it may be more useful to consider the significance of a continuity rather than a change in the seasonality of exploitation. Perhaps we should consider the relationship between the seasonal use of shallow basins for fishing and the development of the *décrue* system rather than relate this to the simple presence of common domestic species.

## Conclusion

Based on the analysis of satellite derived surface models of the Fayum Basin and the location of well-reported archaeological sites, the currently accepted chronostratigraphic schemes for lake advances and retreats can be called into question. The topography of the Fayum north shore shows

the lake edge basins that Caton-Thompson and Gardner (1934) originally identified and indicates that these differ in size and slope with those further to the east being shallower than those to the west. Combining these observations with models of the surface topography of the basin as a whole suggests that relatively small changes in lake levels would alternatively expose or inundate substantial surface areas across the Fayum north shore. Differences in lake edge basin topographies allow inferences to be made concerning the types of palaeoenvironments these basins supported and the types of plants and animals with which they were associated. Of particular significance may be the relationship between basin topography and fish species, particularly in relation to the breeding cycle of clariid catfish and tilapia. Ultimately the Fayum was abandoned around 6 ka. It is interesting to consider the potential relationship between the development of the *décrue* system for cultivation and the seasonality of fish exploitation since both catfish exploitation and use of the Nile inundation for irrigation occurred during the summer.

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## Competing Interests

The authors declare that they have no competing interests.

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