Landscape change in the Nile Delta during the fourth millennium BC: A new perspective on the Egyptian Predynastic and Protodynastic periods

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ABSTRACT

The role environmental change may have played at the dawn of Egyptian history has been overlooked in comparison with other periods. Natural landscape changes taking place in the Nile Delta are argued here to have been a facilitating factor allowing, and possibly stimulating, socioeconomic changes leading to the "Lower Egyptian – Naqada Transition" (LE-NT, *c.* 3350 BC). In this context the LE-NT may be understood in terms of regional elites using newly agrarian delta lands as an agricultural resource and trade route, with the emerging capital, Memphis, ideally situated. We argue (almost counter-intuitively) that a natural reduction in overall landscape productivity led to agricultural intensification through a positive feedback loop. This may have laid the foundations for the emergence of a more unified Egyptian state beginning *c*. 3100 BC. Through this analysis we argue for the incorporation of the environment as an integral component of change narratives of Predynastic Egypt.

Keywords: Lower Egypt, Predynastic, Landscape, Geoarchaeology, Primary productivity, Primary state

1. Introduction

The role that environmental change may have played in guiding socioeconomic and political changes at the dawn of Egyptian history has been largely overlooked. This is despite its well-understood role in setting earlier boundary conditions during the fifth and fourth millennia BC, as well as its later contributions to changes in the Pharaonic period, such as at the end of the Old Kingdom (Butzer 1976; Hassan 1997; Hassan 2010; Butzer 2002; Butzer 2012; Krom et al. 2002; Stanley et al. 2003; Kindermann et al. 2006; Shirai 2010; Welc and Marks 2014). Well-studied sites and regions in both Egypt and Sudan consistently demonstrate that major changes in river hydrology and fluvial landscapes had the potential to impact upon both settlement and subsistence choices (Macklin et al. 2013; van den Brink 1993; Vermeersch and Van Neer 2015; Woodward et al. 2017). In this paper, we argue for the incorporation of environmental change as an integral component of change narratives in Egypt through the late fourth millennium BC.

During this time, fundamental changes were taking place in the Ancient Egyptian social sphere (Stevenson 2016). Power was focused on a group of elites, based on a developing institutional ideology of divine kingship, and authority claimed over a large territorial area (Wengrow 2006; Andelkovič 2008; Bussmann 2014). A "state" entity arose as multiple centres of elite activity in southern (Upper) and northern (Lower) Egypt gave way to a single, larger, territorially defined unit spanning the Nile Valley and Delta. This is 'Dynastic' Egypt – which was centrally ruled from a royal residence or capital at Memphis (Köhler 2008; Köhler 2010; Köhler 2017; Guyot 2011) (Fig. 1). Within this territory, a restrictive ideology authorised newer forms of social relations: storage and manufacturing technologies were placed at the disposal or the elite, while the generation of a food surplus allowed for craft specialization (Yoffee 2005; Cichowski 2008; Campagno 2011; Castillos 2011).

This paper proposes that natural remodelling of the landscapes of the Nile Delta 4000–3000BC, primarily in response to the slowing down of sea-level rise (Pennington et al. 2017), helped stimulate some of the changes that led to the societal transformations. Specifically, an increase in the scale of agricultural practices, the production of an agricultural surplus, population growth and settlement changes, and the emergence of the capital zone at the delta apex can all be considered adaptions to the changing environment. The subsequent transformation of early centres of cultural complexity into the larger political entity of Dynastic Egypt could then have resulted in part from regional elites seeking to control the enormous taxable resource potential of the agrarian delta.

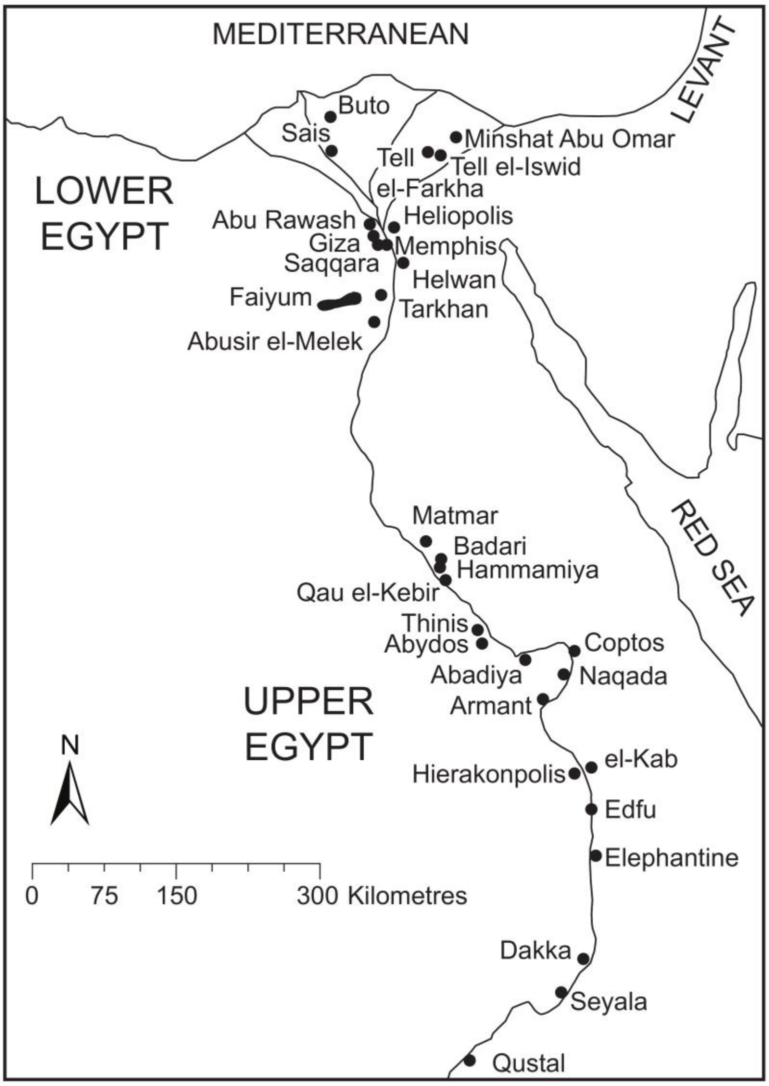

Fig. 1 Map showing selected Predynastic, Protodynastic and Early Dynastic sites in Egypt.

2. Ancient Egyptian Prehistory

The Ancient Egyptian cultural tradition developed from a Neolithic phase (*c.* 5500–3750 BC), through Predynastic (*c.* 3750–3350 BC; Naqada IA–IIC) and Protodynastic (*c.* 3350–3100 BC; Naqada IIIA–B) periods, finally finding its expression as a unified territorial entity which was centrally administered, taxed and ruled during the Dynastic era from *c.* 3100 BC onwards (Midant-Reynes 2000; Wengrow 2006; Dee *et al.* 2013; Tassie 2014). Following migration of people into the fertile valley of the Nile at the end of the African Humid Period *c.* 5500 BC (Kindermann et al. 2006; Kuper and Kröpelin 2006), the Neolithic period in the Valley and Delta was marked by transhumant communities practising low-level food production, combining wild resources with cattle, sheep and goat herding (Wengrow et al. 2014; Holdaway and Phillipps 2017). Cereal agriculture also took place in some places (Phillipps et al. 2012), and pig husbandry, hunting and fishing occurred at peak times of the year (Wilson et al. 2014; Linseele 2014).

During the subsequent Predynastic period, marked changes took place in the social sphere (Naqada IA–IIB). Communities became more sedentary and there was an increased focus on cereal agriculture, with evidence for division of labour (Takamiya 2004; Cichowski 2008). Significant regionality in material culture at the beginning of the period (Friedman 2000) gradually decreased, broadly giving way to two cultural complexes – one in Upper Egypt and another in Lower Egypt (Stevenson 2016). In some places, such as Adaïma and Hierakonpolis in the south, the construction of richly adorned tombs demonstrate clear inequality in the distribution of wealth (Crubézy *et al.* 2002: 560–61; Friedman 2008) and the emergence of regional elites.

A major transformation, the “Lower Egyptian – Naqada Transition” (LE-NT) took place towards the end of this period, *c.* 3350 BC (Naqada IIC–D), during which time there was a large increase in interregional exchange (especially of prestige objects), a spread of aspects of Upper Egyptian material culture into Lower Egypt (Maczyńska 2011), and significant transformations in ceramic production and other technologies (Wengrow 2006, 92–98; Köhler 2014). There was also agrarian intensification in the delta (Wengrow 2006, 156–165). An increase in the archaeologically identifiable number of sites in the delta, especially in the east (Figs. 2 & 3d; see also supplemental material) also points to population growth and changes in settlement style, and suggests the delta was becoming more of a focus for trade and exchange with the Levant, the Uruk region, the western desert and the Mediterranean (Jucha and Maczyńska 2011; von der Way 1986).

It is thought that the LE-NT primarily reflects increasing interregional exchange between people in Upper Egypt, Lower Egypt and the Levant (Maczyńska 2014; Bard 2017, 28). Emergent elites engaging in peer-polity interaction sought to acquire prestige goods as symbols of power and for “consumption” in burials (Wengrow 2006; Köhler 2010, 40). Many such materials (e.g. wood, resin, ceramics) originated from the Levant, so the Nile Delta hosted key transportation routes and became the area in which interactions between Egyptians and people from the eastern Mediterranean were conducted. Such interactions are especially obvious along the edge of the eastern delta (Maczyńska 2014, 30–32) as well as at Buto in the north (Guyot 2008). The gradual process of increasing inter-regional elite activity is thought to have given rise to social integration (Maczyńska 2011, 900) or “acculturation” (Buchez and Midant-Reynes 2007, 852) between Upper and Lower

Egyptians, and ultimately resulted in a new, single cultural complex existing across the territory that was to become Egypt.

Finally, during the Protodynastic period, inter-polity interactions between competing centres of power culminated in political unification *c.* 3100 BC and the establishment of a territorial state encompassing all of Egypt (Wilkinson 2000, 378–379, 392; Andelkovič 2006; Köhler 2008). A new centre of power was set up at Memphis, where a series of elite tombs confirm the eastward-facing early state and continue the development of elaborate funerary practices (Köhler 2016).

The role of the natural environment in presenting opportunities and challenges to the inhabitants of the Nile Valley and Delta through the *earlier* part of this history has been a recurring theme of debate in Egyptian archaeological research. The agricultural basis of society in Ancient Egypt relied primarily upon the annual inundation of the River Nile, fluctuations in the height of which are fairly well understood (Hassan 1981; Butzer 1984; Macklin et al. 2015). The exact dynamics of the resulting irrigation agriculture rested upon the ancient inhabitants having an in-depth understanding of their landscape, and being able to work with it effectively (Butzer 1976; Hassan 1997, 2010). The environment could have dictated favourable places for settlement (often on river levees or sandy hills – Pleistocene "turtlebacks" or "gezira") and helped set boundary conditions as to what sorts of activities were practised in each location (Bietak 1975; van den Brink 1993; Butzer 2002). Over the longer-term (hundreds-to-thousands of years), adaptions to long-term climatic changes were also involved in stimulating migrations, agricultural innovations and specific changes at archaeological sites (Kindermann et al. 2006; Shirai 2010; Clarke et al. 2016; Woodward et al. 2017).

However, recent work has shown that there were significant, previously unconsidered, landscape changes taking place within the Nile Delta through the fourth millennium BC as well (Pennington et al. 2017). It is proposed that this environmental evolution may also have contributed specifically to some of the important social changes taking place during the Predynastic and Protodynastic periods.

3. Environmental changes in the Nile Delta

Dynamic geo-landscape modelling shows that through the fourth millennium BC, during the Predynastic and Protodynastic phases of Egyptian civilization, there were substantial, albeit gradual, environmental changes taking place in the Nile Delta (Pennington et al. 2016; Pennington et al. 2017). These landscape changes (Fig. 2), can broadly be summarized as a transition from "Large-Scale Crevassing" (LSC) environments, comprising dynamic, multichannel anastomosing river systems, poorly drained floodbasins and swampy marshland environments, to "Meandering" landscapes of wider, more homogenous, well-drained floodplains and single-channel river networks (see supplemental material for more details). This "LSC-Meandering Transition" (LSC-MT) was driven predominantly by a slowing down of relative sea-level rise within the context of weakening river discharge and sediment supply (Pennington et al. 2017). At the same time, Pleistocene "turtlebacks" became smaller in extent as the delta plain aggraded. The LSC-MT took place in a time-transgressive fashion (Fig. 2), initially in the southern half of the delta *c.* 4000–3500 BC, and then in the northern delta through the remainder of the fourth millennium and – in the extreme north – to *c.* 2500 BC (Pennington et al. 2017).

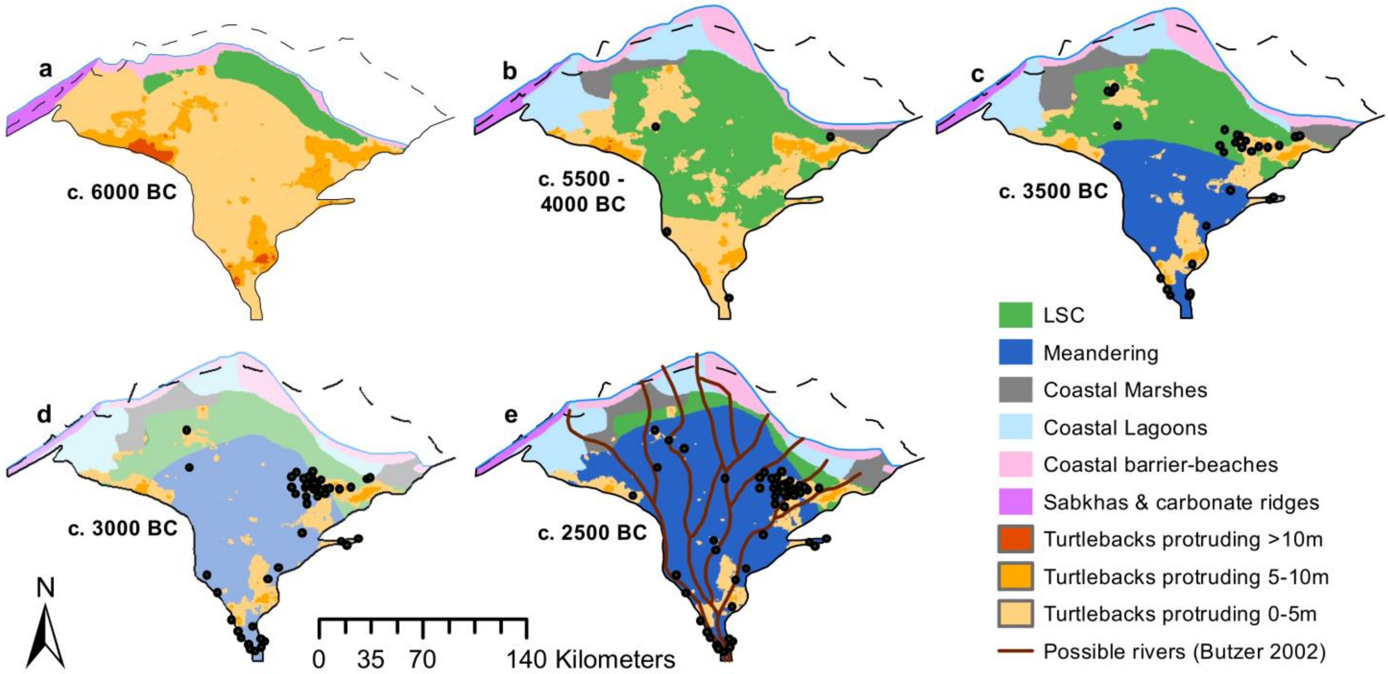

Fig. 2 Changing landscapes (Pennington et al. 2017) and known sites in the Nile Delta through time: a) 6000 BC; b) 5500–4000 BC; c) 3500 BC; d) 3000 BC; e) 2500 BC. The landscapes at 3000 BC (faded colour) were not originally modelled, but are estimated here by averaging those at 3500 BC and 2500 BC. Speculative locations of the main river branches are also shown, after Butzer (2002). There may also have been a waterway eastwards, through the Wadi Tumilat.

These landscape changes were arguably the major environmental shifts taking place within the Ancient Egyptian cultural sphere at this time (Macklin et al. 2013; Macklin and Lewin 2015), and should be considered in any discussion of contemporaneous social developments, not least because of the size of the delta region, then constituting approximately 1.4 times the amount of potentially cultivatable land as Upper Egypt (see supplemental material). This paper contends that the environmental changes may have helped to stimulate changes in economic management strategies through the Predynastic and Protodynastic periods of Ancient Egypt, which then could have brought about specific social and political responses. The discussion below considers four interlinked "adaptions" in turn:

1. Increased agricultural output in the delta may have been both *stimulated* and *enabled* by these landscape changes.
2. In turn, this would have given opportunity for the production of a surplus, which may have further resulted in a positive feedback loop of population growth and an increased focus on sedentism.
3. The environmental changes may also have helped facilitate the focussing of political power to the delta apex: the foundation and growth of Memphis.
4. Ongoing societal changes allied to all these developments may have aided the transformation that took place through the LE-NT and the Protodynastic period, whereby all of Egypt ultimately came under single political control.

4. Increase in agricultural output of the delta

Increased uptake of agricultural technologies in the delta may have occurred as the natural landscapes became less productive, and the delta inhabitants were forced to innovate to compensate. Each different landscape type intrinsically hosts a different amount of organic resources (food, biomass) that can be exploited by people: a quantity that can be calculated as the total potential Net Primary Productivity (NPP_{pot}) of the environment (Lieth and Whittaker 1975; Haberl et al. 2014, 2016). Such a changing total potential resource base (total ecosystem NPP_{pot}) can be estimated for the entire Nile Delta through time by calculating the areas of the different types of environments covering the delta plain at different times (Fig. 2), assigning each of these landscape types a characteristic value for NPP_{pot} (Table 1), and multiplying through (see supplemental material for full details). We can calculate that through the mid-Holocene, the total potential organic resource base (total NPP_{pot}) for the whole delta decreased by some 45%, as high-NPP_{pot} LSC landscapes gave way to lower-NPP_{pot} “Meandering” environments (Figs. 3a, 3b).

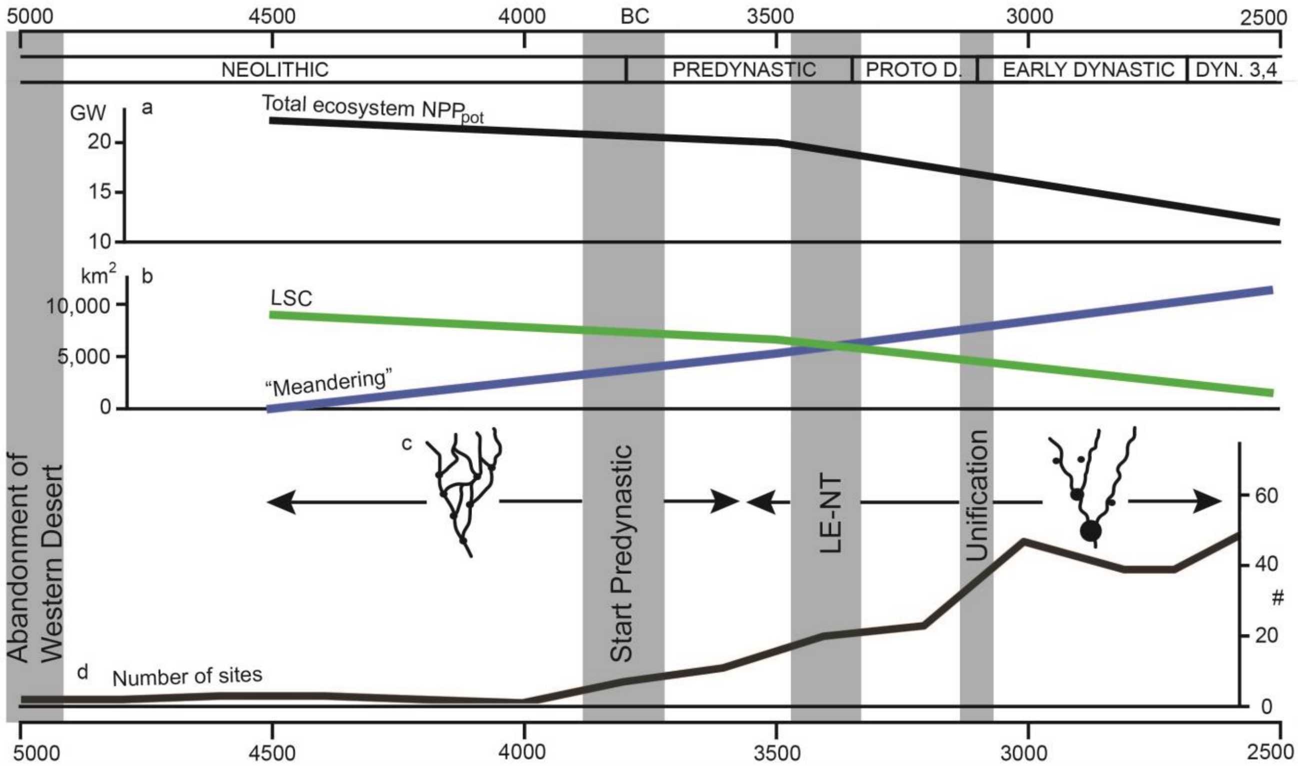

Fig. 3 Timeline showing shifts in the Nile Delta through the mid-Holocene. a) Changing total “power” of ecosystem (total ecosystem NPP_{pot}) summed across the whole delta in GW; b) Changing areal extent of LSC and “Meandering” environments within the delta; c) Schematic river network – the size of the dot at each node indicates the connectivity of that node; d) Number of known archaeological sites in the delta. See supplemental material for full explanation of the construction of this figure.

Table 1. Average NPP_{pot} values for different landscape types based upon assumed ecosystem types (see supplemental material for full details).

Mapped unit	Ecosystems/environment	NPP_{pot} mean (W/m^2)	NPP_{pot} range (W/m^2)	Reference
LSC	Papyrus swamps, freshwater marshes, open water	1.94	0.95–3.06	See supplemental material
"Meandering"	Grassland, woodland, shrubland	0.41	0.14–0.87	Lieth & Whittaker (1975)
Turtlebacks within floodplain	Desert, semidesert scrub	0.06	0.01–0.16	Lieth & Whittaker (1975)
Geziracover	Grassland, woodland, shrubland	0.41	0.14–0.87	Lieth & Whittaker (1975)
Coastal beach sands	Dune vegetation	0.05	0.05	Cardoch et al. (2002)
Sabkha and coastal ridges	Hypersaline lagoon	0.91	0.91	Yáñez-Arancibia et al. (2007)
Coastal wetlands	Salt marshes, brackish marshes	2.35	1.9–2.79	Day et al. (1997); Yáñez-Arancibia et al. (2007)
Lagoons	Lake and stream	0.25	0.06–0.95	Lieth & Whittaker (1975)
Open sea	Continental shelf	0.23	0.13–0.38	Lieth & Whittaker (1975)

In order to counter such a decrease in available organic resources, human societies would have been required to increase their efficiency of extraction, through increased uptake of agricultural technologies (or they could have chosen to migrate). From the available NPP_{pot} in any environment, people directly co-opt a portion termed the "Human Appropriation of Net Primary Productivity via Harvest" ($HANPP_{harv}$), by taking food and biomass from the environment into human society (Haberl et al. 2014, 2016). If NPP_{pot} were to decrease, in order to harvest the same total quantity of resources (keep $HANPP_{harv}$ constant) and thus support the same population size, people would have had to adopt a more efficient method of resource transfer, thus increasing the ratio $HANPP_{harv}/NPP_{pot}$ (Fig. 4). The increase in efficiency which would have been required to compensate for the decrease in NPP_{pot} in the Nile Delta would have been approximately 1.85x (see supplemental material). Increased adoption of agricultural methods is a way of increasing this efficiency of transfer (Krausmann, Weisz, and Eisenmenger 2016, 70), and could therefore be seen as a social adaption to the decrease in NPP_{pot} driven by the landscape changes.

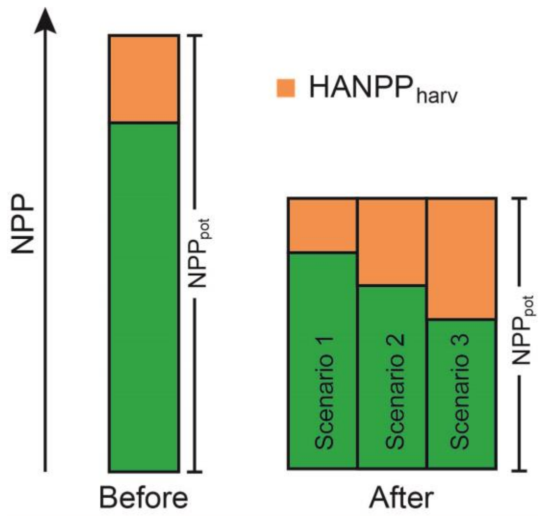

Fig. 4 Schematic showing potential human responses to a decrease in NPP_{pot} ("Potential Net Primary Productivity" of the environment). In scenario 1, no technological or behavioural changes are made to food collection strategies, and $HANPP_{harv}$ ("Human Appropriation of Net Primary Productivity via Harvest" – i.e. total resources taken from the environment) is still the same percentage of NPP_{pot} as before. In scenario 2, humans adapt to the decrease by appropriating technologies that increase their efficiency of resource collection such that the same total quantity of $HANPP_{harv}$ is maintained. In scenario 3 the technological changes result in a greater quantity of $HANPP_{harv}$ than before; this is thought to be the case in the prehistoric Nile Delta (see text).

Such an increased adoption of agricultural practices is indeed observed in the delta through the LSC-MT. There is a major increase in the abundance of pig bones found at archaeological sites within the later "Meandering" landscapes when compared to those from the LSC environment, and a corresponding decrease in catfish remains (see supplemental material), perhaps pointing towards a shift from lifestyles centred around the harvesting of aquatic resources towards strategies more focussed on the rearing of domestic stock. Cereal agriculture is also thought to have become more dominant through the Predynastic period (Midant-Reynes 2000, 254–255; Fahmy 2004; Chłodnicki et al. 2012; Tassie 2014, 357–359) as evidenced by increased numbers of bread moulds, serving and storage vessels for grain, and changes in the stone-tool assemblage (Wengrow 2006, 160–163). To some extent, therefore, the increases in agricultural practices can be thought of as being partially *stimulated* by this reduction in NPP_{pot} through the LSC-MT.

The shift towards more intense pastoral and cereal agriculture can also be seen as having been *enabled* by other aspects of the landscape changes (Fig. 5). The narrow levees and extensive swamps present in the LSC environment would have imposed major size restrictions on field systems, in contrast to the later "Meandering" landscapes which would have been much more conducive to agriculture. The more expansive, homogenous, and well-drained floodplain environments of the "Meandering" regime would have allowed for larger areas of land where cereals and other crops such as flax could be planted and tended between waterway branches, as well as more extensive areas of land on which domesticated stock could be herded and pastured. It is likely that the western and northern margins of the delta were used for stock (e.g. cattle) while the centre and east may have been more arable (Wenke et al. 2016). Crops would have been watered through early irrigation systems such as those depicted on the Scorpion macehead (Fig. 6), which features a Protodynastic king ceremonially digging an irrigation ditch (Butzer 1976, 20–21). Inspiration and technological know-how for some of the changes may have come from Upper Egypt, where the floodplain was already a more tightly-organized agricultural system (Butzer 1976; Hassan 2010, 12–13).

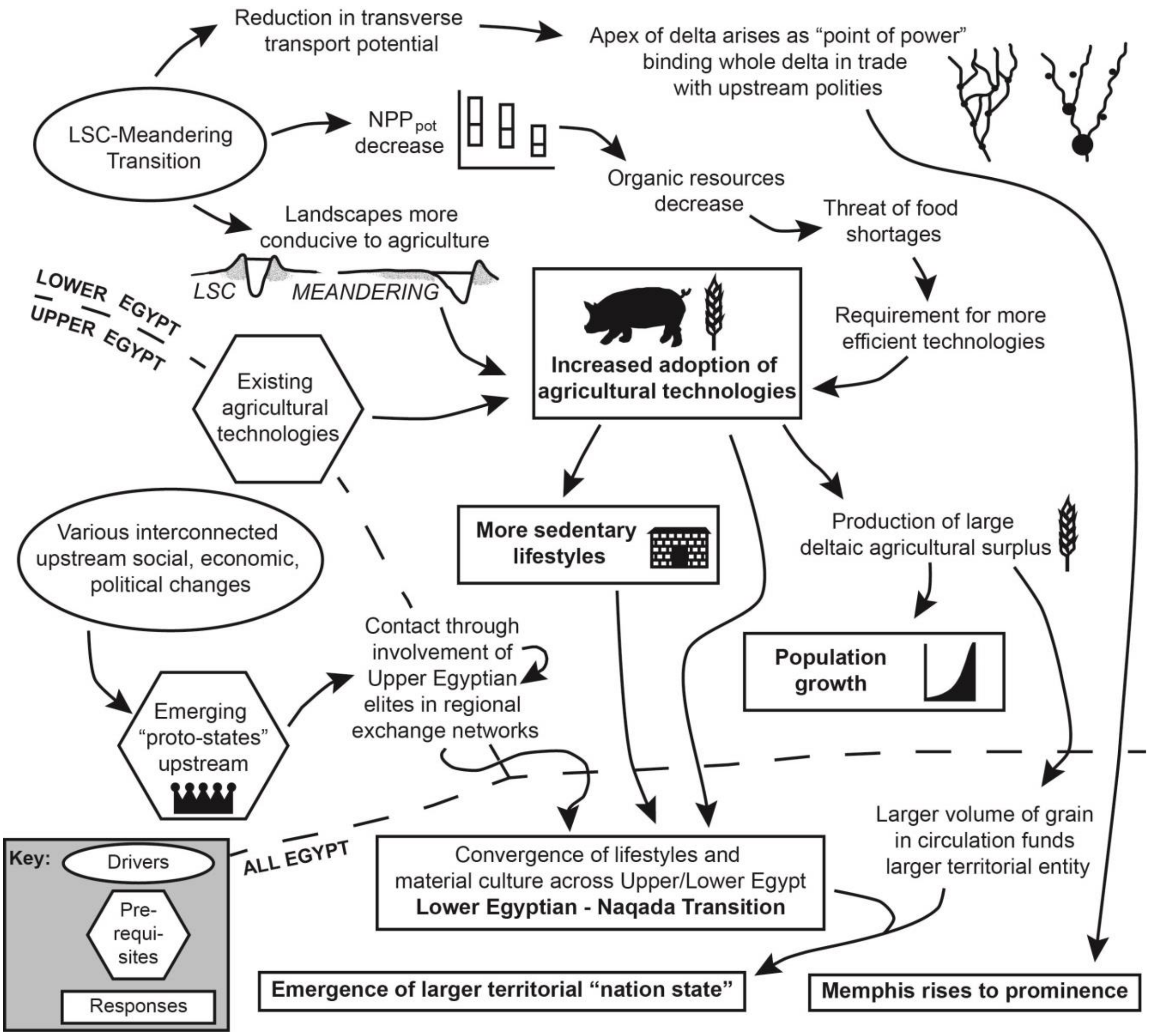

Fig. 5 An environmental perspective on the development of Lower Egypt and the emergence of the Ancient Egyptian State.

Thus, the observed shift in the Nile Delta during the fourth millennium BC from a lifestyle based predominantly around fishing to one characterized by the intensification of cereal agriculture and domestic stock-keeping can be partially interpreted as having been facilitated or even stimulated by a reduction in the total productivity of the natural environment through the LSC-MT, and enabled by other aspects of landscape change rendering the environment more conducive to mixed agriculture (Fig. 5).

Fig 6. The Scorpion macehead, featuring a Protodynastic king ceremonially digging an irrigation ditch, most likely in southern Egypt. Line drawing of the relief on AN1896-1908 E.3632 Mace-head of Scorpion king. Image © Ashmolean Museum, University of Oxford.

5. Production of an agricultural surplus, population growth and increased sedentism

Following on from the methodology above, it is also quantifiably possible to show that an agricultural surplus would have been produced in the Nile Delta once the transformation discussed above had occurred. The decrease in landscape NPP_{pot} required an increase in the efficiency of resource-collection by 1.85x (see supplemental material), but the shift towards agricultural technologies may have actually increased this efficiency by up to two or three orders of magnitude (Krausmann 2011, 70), far more than was necessary (Fig. 4). As such, a surplus would have been produced, which could have been used to fund population growth and division of labour through a positive feedback mechanism (Fig. 5).

Furthermore, more agricultural lifestyles would have resulted in seasonal mobility becoming less advantageous (Yokell 2004, 66). The requirement to tend crops and store larger surpluses would have been a factor inducing people to stay in one place, high and dry from the annual Nile flood. “Geziras”, lying above the level of the Nile flood, would have been ideal places for longer-term settlement or activity.

A shift towards such sedentism may be reflected by an increase in the number of known sites between 4000 and 3000 BC (Fig. 3d). Although these sites are disparate in type – some settlements, others cemeteries – the observed increase most likely results from a broad shift towards a more sedentary lifestyle (perhaps coupled with population growth). The more permanent localization of activities in particular areas would have created larger and more permanent "sites" that tend to be better-preserved, and are therefore recorded in larger numbers today.

6. Focussing of political power to the delta apex

From the later Predynastic period onwards (*c.* 3500–3000 BC), a large number of sites also came into being specifically at the delta apex (Fig. 2); by the first dynasty this area – the Memphite region – had become the most important location in Egypt, where substantial monumental architecture was built and the royal court was based (Love 2003, 70). This area was naturally becoming more important since trade between Upper and Lower Egypt was increasing through this time period (Maczyńska 2014, 30). However, the landscape changes taking place within the delta also could have made this location even more advantageous. Within the LSC environment, the plethora of transport routes from any node in the network to any other, through the large number of interconnected channels in the distributary system, meant that there would have been no major trade advantage for a settlement in any position (Fig. 3c). But after the LSC-MT, with the reduction of the transverse transport potential formerly afforded by the anastomosing river distributaries, there would have arisen a powerful point in the landscape – a node at the apex through which transverse, upstream, and downstream trade had to pass.

Geoarchaeological coring studies have shown that around 2000 BC this nodal point – the "head" of the delta – was some 40km further south than it is today, near the sites of Maadi, El Omari, Gerzeh, Helwan and of course Memphis (Jeffreys 1985; Bunbury et al. 2017). It was in this location that the Egyptian capital zone became established at approximately the beginning of the first dynasty, *c.* 3100 BC. Memphis itself may have been just north of the nodal point, surrounded by a number of strategically-close-together channels, constrained by the narrow valley of the Nile (Bunbury et al. 2017).

7. The LE-NT and the subsequent transformation into Dynastic Egypt

It is proposed above that an increase in agricultural practices in early Lower Egypt, the production of a surplus, a shift towards sedentary settlement on turtlebacks/gezira in the delta region, and the focussing of power towards the delta apex can all be understood within the framework of a changing social-ecological system following the landscape shifts associated with the LSC-MT. These socioeconomic changes in the delta could also have had some wider bearing on contemporary sociocultural developments throughout the Nile system, in which centres of early social complexity became transformed into the larger territorial political entity covering all Egypt (Fig. 5).

Through the Predynastic period, as elites from all over Egypt were becoming increasingly involved in the delta region, using it to source prestige materials from the Levant (Maczyńska 2014, 28–32), the deltaic landscapes were gradually being remodelled (through the LSC-MT) from a series of swampy environments very different to those which existed in Upper Egypt, to "Meandering" ones that afforded similar opportunities to those provided by the floodplain further upstream. The inhabitants of the delta may have looked to their contemporaries in Upper Egypt in deciding which strategies to adopt in order to deal with these changes. The inspiration for increased cereal agriculture may have come from upstream, for example. By the time that the delta plain comprised mostly "Meandering" environments in the second half of the fourth millennium BC, both Upper and Lower Egypt had converged not only in terms of the natural environment but also in terms of the subsistence strategies and settlement styles adopted by their inhabitants. In this scenario, the LE-NT was a semi-predictable consequence: increased cultural interconnectivity within convergently evolving landscapes gave rise to the alignment of both lifestyles and material culture across the region.

Crucially, however, Lower Egypt was significantly larger in geographical area than Upper Egypt, containing 1.4 times as much potentially cultivatable land (14,000km^2), as well as resource-rich marsh areas at the fringes. During the Protodynastic era, the political authorities in the more spatially restricted floodplains further upstream would have recognized the potentially enormous taxable basis of the delta region, now that it was involved in greater production of food. As such, they may have sought to realize it for their own benefit, recognizing that the economic foundations of political authority increasingly lay within the delta. Initially, this was accomplished through the economic and political unification of Upper and Lower Egypt, but the process continued through the Old Kingdom as the royal court and state temples gradually brought the delta's production under increasingly direct control through a process of "internal colonization" (Kemp 1983; Małecka-Drozd 2014, 59–60), ensuring that its surplus was engaged in supporting the state structure. This is well illustrated, for instance, by meat from Kom el-Hisn being used to supply the workmen's village at Giza (Wenke et al. 2016).

The administrative centre of the resulting polity was ideally located at the delta apex. Binding together the agriculturally productive delta with centres of culture further upstream (as well as potentially having links to the Sinai and Red Sea through the Wadi Tumilat), this location was now also the point at which all transverse delta traffic now had to pass. Memphis was thus established in this position once the environmental changes associated with the LSC-MT had been completed.

8. Conclusions

During the late fourth millennium BC, one of the world's first states emerged within the Nile Valley and Delta, as small, regionally diverse centres of culture became transformed into the much larger, single territorial entity of Dynastic Egypt. This transformation was at least facilitated but may have even been stimulated by a natural remodelling of the delta landscapes, which gradually resulted in similar sets of lifestyles becoming advantageous in both Upper and Lower Egypt. Older deltaic lifestyles centred around fishing gave way to new agricultural realities, settled lifestyles and population growth. Emergent elites then recognized the enormity of the newly agrarian delta's grain surplus and sought to realize it for their own benefit, binding together Upper and Lower Egypt in a singly administered and taxed entity as they did so. This "Primary State" existed for nearly a thousand years before internal factors and external pressures caused it to collapse at the end of the Old Kingdom. The role of environmental change in setting boundary conditions for socioeconomic trajectories and promoting local innovation must not be overlooked at this crucial juncture at the dawn of history.

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References

Andelkovič, Branislav. 2006. "Models of State Formation in Predynastic Egypt." In *Archaeology of Early Northeastern Africa: In Memory of Lech Krzyzaniak*, edited by Karla Kroeper, M Chłodnicki, and M Kobusiewicz, 593–609. Poznań: Poznań Archaeological Museum.

Andelkovič, Branislav. 2008. "Parameters of Statehood in Predynastic Egypt." In *Egypt at Its Origins 2: Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'', Toulouse, 5th -- 8th September 2005.*, edited by Béatrix Midant-Reynes and Yann Tristant, 1039–1056. Leuven: Peeters.

Bard, Kathryn A. 2017. "Political Economies of Predynastic Egypt and the Formation of the Early State." *Journal of Archaeological Research* 25 (1): 1–36. doi:10.1007/s10814-016-9095-6.

Bietak, Manfred. 1975. *Tell El-Dab'a II: Der Fundort Im Rahmen Einer Archäologisch-Geographischen Untersuchung Über Das Ägyptische Ostdelta*. Vienna: Verlag der Österreichischen Akademie der Wissenschaften.

Buchez, Nathalie, and Béatrix Midant-Reynes. 2007. "Le Site Prédynastique de Kom El-Khilgan (Delta Oriental). Données Nouvelles Sur Les Processus d'unification Culturelle Au IVe Millénaire." *Bulletin de l'Institut Français d'Archéologie Orientale* 107: 43–70.

Bunbury, J M, Ana Tavares, B T Pennington, and P Gonçalves. 2017. "Development of the Memphite Floodplain - Landscape and Settlement Symbiosis in the Egyptian Captial Zone." In *The Nile: Natural and Cultural Landscape in Egypt.*, edited by Harco Willems and Jan-Michael Dahms, 71–96. Bielefeld: Transcript Verlag.

Bussmann, R. 2014. "Scaling the State." *Archaeology International* 17: 79–93.

Butzer, K W. 1976. *Early Hydraulic Civilization in Egypt*. Chicago: University of Chicago Press.

Butzer, K W. 1984. "Long-Term Nile Flood Variation and Political Discontinuities in Pharaonic Egypt." In *From Hunters to Farmers*, edited by J D Clark and S A Brandt, 102–112. Berkeley: University of California Press.

Butzer, K W. 2002. "Geoarchaeological Implications of Recent Research in the Nile Delta." In *Egypt and the Levant: Interrelations from the 4th through the Early 3rd Millennium BCE*, edited by E C M van den Brink and T E Levy, 83–97. London: Leicester University Press.

Butzer, K W. 2012. "Collapse, Environment, and Society." *PNAS* 109 (10): 3632–3639.

Campagno, Marcelo. 2011. "Kinship, Concentration of Population and the Emergence of the State in the Nile Valley." In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 1229–1242. Leuven: Peeters.

Cardoch, L, John W Day, and C Ibañez. 2002. “Net Primary Productivity as an Indicator of Sustainability in the Ebro and Mississippi Deltas.” *Ecological Applications* 12 (4): 1044–1055.

Castillos, J J. 2011. “The Development and Nature of Inequality in Early Egypt.” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 1243–1253. Leuven: Peeters.

Chłodnicki, M, K M Ciałowicz, and A Maczyńska. 2012. *Tell El-Farkha I: Excavations 1998--2011*. Poznań: Poznań Archaeological Museum.

Cichowski, K. 2008. “The Brewery Complex from Tell El-Farkha. Archaeological Aspects of the Discovery.” In *Egypt at Its Origins 2: Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'', Toulouse, 5th -- 8th September 2005.*, edited by Béatrix Midant-Reynes and Yann Tristant, 33–40. Leuven: Peeters.

Clarke, Joanne, Nick Brooks, Edward B Banning, Miryam Bar-Matthews, Stuart Campbell, Lee Clare, Mauro Cremaschi, et al. 2016. “Climatic Changes and Social Transformations in the Near East and North Africa during the `long’ 4th Millennium BC: A Comparative Study of Environmental and Archaeological Evidence.” *Quaternary Science Reviews* 136: 96–121.

Crubézy, E, T Janin, and B Midant-Reynes. 2002. *Adaima 2. La Nécropole Prédynastiqye*. Cairo: Institut Français d’Archéologie Orientale.

Day, John W, Jay F Martin, Lynette Cardoch, and Paul H Templet. 1997. “System Functioning as a Basis for Sustainable Management of Deltaic Ecosystems.” *Coastal Management* 25 (2). Taylor & Francis: 115–153. doi:10.1080/08920759709362315.

Dee, Michael, David Wengrow, Andrew Shortland, Alice Stevenson, Fiona Brock, Linus Girdland Flink, and Christopher Bronk Ramsey. 2013. “An Absolute Chronology for Early Egypt Using Radiocarbon Dating and Bayesian Statistical Modelling.” *Proceedings of the Royal Society of London A: Mathematical, Physical and Engineering Sciences* 469 (2159): 1–10.

Fahmy, A G. 2004. “Insights on the Development of Archaeobotanical and Palaeothnobotanica.” In *Egypt at Its Origins: Studies in Memory of Barbara Adams. Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'', Kraków, 28th August -- 1st September 2002*, edited by S Hendrickx, R Friedman, K M Ciałowicz, and M Chłodnicki, 711–730. Leuven: Peeters.

Friedman, R. 2008. “Excavating Egypt’s Early Kings: Recent Discoveries in the Elite Cemetery at Hierakonpolis.” In *Egypt at Its Origins 2: Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'', Toulouse, 5th -- 8th September 2005.*, edited by B Midant-Reynes and Yann Tristant, 1157–1194. Leuven: Peeters.

Friedman, R F. 2000. “Regional Diversity in the Predynastic Pottery of Upper Egyptian Settlements.” In *Recent Research into the Stone Age of Northeastern Africa*, edited by L Krzyzaniak, Karla Kroeper, and Michal Kobusiewicz, 171–186. Poznań: Poznań Archaeological Museum.

Guyot, F. 2008. “The Origins of the ‘Naqadan Expansion’ and the Interregional Exchange Mechanisms between Lower Nubia, Upper and Lower Egypt, the South Levant and North Syria during the First Half of the 4th Millennium B.C.” In *Egypt at Its Origins 2: Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'' Toulouse, 5th-8th September 2005.*, edited by Béatrix Midant-Reynes and Yann Tristant, 707–740. Leuven: Peeters.

Guyot, F. 2011. “Primary and Secondary Social Evolutions from the Nile Valley to the Northern Negev in the Mid 4th Millennium BC.” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 1255–1270. Leuven: Peeters.

Haberl, H, K H Erb, and Fridolin Krausmann. 2014. “Human Appropriation of Net Primary Production: Patterns, Trends, and Planetary Boundaries.” *Annual Review of Environment and Resources* 39: 363–391.

Haberl, H, Marina Fischer-Kowalski, Fridolin Krausmann, and Verena Winiwarter. 2016. *Social Ecology: Society-*

Nature Relations across Time and Space. Switzerland: Springer.

Hassan, F A. 1981. "Holocene Nile Floods and Their Implications for Climatic Change." *Science* 212 (4499): 1142–1145.

Hassan, F A. 1997. "The Dynamics of a Riverine Civilization: A Geoarchaeological Perspective on the Nile Valley, Egypt." *World Archaeology* 29 (1): 51–74.

Hassan, F A. 2010. "Climate Change, Nile Floods and Riparia." In *Riparia Dans l'Empire Romain: Pour La Définition Du Concept*, edited by Ella Hermon, 1–20. Oxford: John and Erica Hedges Ltd.

Holdaway, S, and R Phillipps. 2017. "Human Environment Interrelationships and the Origins of Agriculture in Egypt and Sudan." *Oxford Research Encyclopedia, Environmental Science*. doi:10.1093/acrefore/9780199389414.013.177.

Jeffreys, D G. 1985. *The Survey of Memphis*. London: Egypt Exploration Society.

Jucha, M, and A Maczyńska. 2011. "Settlement Sites in the Nile Delta." *Archéo-Nil* 21: 33–50.

Kemp, B J. 1983. "Old Kingdom, Middle Kingdom and Second Intermediate Period c. 2686-1552 BC." In *Ancient Egypt: A Social History*, edited by B G Trigger, B J Kemp, D O'Connor, and A B Lloyd, 71–182. Cambridge: Cambridge University Press.

Kindermann, K, O Bubenzer, S Nussbaum, H Riemer, F Darius, N Pöllath, and U Smettan. 2006. "Palaeoenvironment and Holocene Land Use of Djara, Western Desert of Egypt." *Quaternary Science Reviews* 25 (13–14): 1619–1637.

Köhler, E C. 2008. "The Interaction between and the Roles of Upper and Lower Egypt in the Formation of the Egyptian State. Another Review." In *Egypt at Its Origins 2: Proceedings of the Second Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by B Midant-Reynes and Yann Tristant, 515–543. Leuven: Peeters.

Köhler, E C. 2010. "Theories of State Formation." In *Egyptian Archaeology*, edited by W Wendrich, 36–54. Chichester: Wiley-Blackwell.

Köhler, E C. 2014. "Of Pots and Myths: Attempting a Comparative Study of Funerary Pottery Assemblages in the Egyptian Nile Valley during the Late 4th Millennium BC." In *The Nile Delta as a Centre of CUltural Interactions between Upper Egypt and the Levant in the Fourth Millennium BC*, edited by A Maczyńska, 155–180. Poznań: Poznań Archaeological Museum.

Köhler, E C. 2016. "Helwan: Einblicke in Eine Nekropole Der Stadt Memphis." *Antike Welt* 1: 27–34.

Köhler, E C. 2017. "The Development of Social Complexity in Early Egypt. A View from the Perspective of the Settlements and Material Culture of the Nile Valley." *Agypen Und Levante* 27: 335–356.

Krausmann, Fridolin. 2011. "The Global Metabolic Transition: A Historical Overview." In *The Socio-Metabolic Transition: Long Term Historical Trends and Patterns in Global Material and Energy Use*, edited by F Krausmann, 74–102. Vienna: Institute of Social Ecology Faculty for Interdisciplinary Studies.

Krausmann, Fridolin, Helga Weisz, and Nina Eisenmenger. 2016. "Transitions in Sociometabolic Regimes throughout Human History." In *Social Ecology: Society-Nature Relations across Time and Space*, edited by H Haberl, Marina Fischer-Kowalski, Fridolin Krausmann, and Verena Winiwarter, 63–92. Switzerland: Springer.

Krom, M D, D J Stanley, R A Cliff, and J C Woodward. 2002. "Nile River Sediment Fluctuations over the Past 7000 Yr and Their Key Role in Sapropel Development." *Geology* 30 (1): 71–74.

Kuper, R, and S Kröpelin. 2006. "Climate-Controlled Holocene Occupation in the Sahara: Motor of Africa's Evolution." *Science* 313 (5788): 803–807.

Lieth, H, and R H Whittaker. 1975. *Primary Productivity of the Biosphere*. Berlin: Springer-Verlag.

Linseele, Veerle. 2014. "Fish Remains from Neolithic Contexts." In *Sais II: The Prehistoric Period*, edited by

Penelope Wilson, G Gilbert, and Geoff J Tassie, 141–148. London: Egypt Exploration Society.

Love, S. 2003. “Questioning the Location of the Old Kingdom Capital of Memphis, Egypt.” *Papers from the Institute of Archaeology* 14: 70–84.

Macklin, Mark G, and John Lewin. 2015. “The Rivers of Civilization.” *Quaternary Science Reviews* 114: 228–244.

Macklin, Mark G, Willem H J Toonen, Jamie C Woodward, Martin A J Williams, C Flaux, Nick Marriner, Kathleen Nicoll, Gert Verstraeten, Neal Spencer, and Derek Welsby. 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.” *Quaternary Science Reviews* 130: 109–123.

Macklin, Mark G, Jamie C Woodward, Derek Welsby, G A T Duller, Frances M Williams, and M A J Williams. 2013. “Reach-Scale River Dynamics Moderate the Impact of Rapid Holocene Climate Change on Floodwater Farming in the Desert Nile.” *Geology* 41 (6): 695–698.

Maczyńska, A. 2011. “The Lower Egyptian-Naqada Transition: A View from Tell El-Farkha.” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 879–908. Leuven: Peeters.

Maczyńska, A. 2014. “The Nile Delta as a Center of Cultural Interaction between Upper Egypt and the Southern Levant in the 4th Millennium BC.” *Studies in Ancient Art and Civilization* 18: 25–46.

Małecka-Drozd, Natalia. 2014. “The Settlement Landscape in the Nile Delta of the 3rd Millenium BC.” In *Aegyptus Est Imago Caeli*, edited by Mariusz A. Jucha, Joanna Debowska-Ludwin, and Piotr Kolodziejczyk, 57–62. Krakow: Institute of Archaeology, Jagiellonian University.

Midant-Reynes, B. 2000. *The Prehistory of Egypt: From the First Egyptians to the First Pharaohs*. Malden: Blackwell Publishing.

Pennington, B T, J M Bunbury, and N Hovius. 2016. “Emergence of Civilisation, Changes in Fluvio-Deltaic Styles and Nutrient Redistribution Forced by Holocene Sea-Level Rise.” *Geoarchaeology* 31 (3): 194–210.

Pennington, B T, Fraser Sturt, Penelope Wilson, Joanne Rowland, and Antony G Brown. 2017. “The Fluvial Evolution of the Holocene Nile Delta.” *Quaternary Science Reviews* 170: 212–231.

Phillipps, R, S Holdaway, W Wendrich, and R Cappers. 2012. “Mid-Holocene Occupation of Egypt and Global Climatic Change.” *Quaternary International* 251: 64–76.

Shirai, N. 2010. *The Archaeology of the First Farmer-Herders in Egypt: New Insights into the Fayum Epipalaeolithic and Neolithic*. Leiden: Leiden University Press.

Stanley, D J, M D Krom, R A Cliff, and J C Woodward. 2003. “Nile Flow Failure at the End of the Old Kingdom, Egypt: Strontium Isotope and Petrologic Evidence.” *Geoarchaeology* 18 (3): 395–402.

Stevenson, Alice. 2016. “The Egyptian Predynastic and State Formation.” *Journal of Archaeological Research* 24 (4): 421–468.

Takamiya, I H. 2004. “Development of Specialisation in the Nile Valley during the 4th Millennium BC.” In *Egypt at Its Origins: Studies in Memory of Barbara Adams. Proceedings of the International Conference ``Origin of the State. Predynastic and Early Dynastic Egypt'', Kraków, 28th August -- 1st September 2002*, edited by S Hendrickx and R.F. Friedman, 1027–1039. Leuven: Peeters.

Tassie, G J. 2014. *Prehistoric Egypt: Socioeconomic Transformations in North-East Africa from the Last Glacial Maximum to the Neolithic, 24,000-4,000BC*. London: Golden House Publications.

van den Brink, E C M. 1993. “Settlement Patterns in the Northeastern Nile Delta during the Fourth-Second Millennia BC.” In *Environmental Change and Human Culture in the Nile Basin and Northern Africa until the 2nd Millennium B.C.*, edited by L Krzyzaniak, M Kobusiewicz, and J Alexander, 279–304. Poznań: Poznań Archaeological Museum.

Vermeersch, Pieere M, and Wim Van Neer. 2015. “Nile Behaviour and Late Palaeolithic Humans in Upper Egypt during the Late Pleistocene.” *Quaternary Science Reviews* 130: 155–167.

von der Way, T. 1986. “Tell El-Fara’in Buto. 2. Bericht.” *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 43: 241–257.

Welc, F, and L Marks. 2014. “Climate Change at the End of the Old Kingdom in Egypt around 4200 BP: New Geoarchaeological Evidence.” *Quaternary International* 324: 124–133.

Wengrow, David. 2006. *The Archaeology of Early Egypt: Social Transformations in North-East Africa, c. 10,000 to 2,650 BC*. Cambridge: Cambridge University Press.

Wengrow, David, Michael Dee, Sarah Foster, Alice Stevenson, and Christopher Bronk Ramsey. 2014. “Cultural Convergence in the Neolithic of the Nile Valley: A Prehistoric Perspective on Egypt’s Place in Africa.” *Antiquity* 88 (339): 95–111.

Wenke, Robert J, Richard W Redding, and Anthony J Cagle. 2016. *Kom El-Hisn (ca. 2500 -- 1900 BC): An Ancient Settlement in the Nile Delta of Egypt*. Atlanta: Lockwood Press.

Wilkinson, T A H. 2000. “Political Unification: Towards a Reconstruction.” *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 56: 377–395.

Wilson, P, G Gilbert, and G Tassie. 2014. *Sais II: The Prehistoric Period*. London: Egypt Exploration Society.

Woodward, J, M Macklin, N Spencer, M Binder, M Dalton, S Hay, and A Hardy. 2017. “Living with a Changing River and Desert Landscape at Amara West.” In *Nubia in the New Kingdom: Lived Experience, Pharaonic Control and Indigenous Traditions. British Museum Publications on Egypt and Sudan 3*, edited by N Spencer, A Stevens, and M Binder, 227–257. Leuven: Peeters.

Yáñez-Arancibia, Alejandro, Ana Laura Lara-Domínguez, Patricia Sánchez-Gil, and John W Day. 2007. “Estuary-Sea Ecological Interactions: A Theoretical Framework for the Management of Coastal Environment.” In *Environmental Analysis of the Gulf of Mexico*, edited by K Withers and M Nipper, 271–301. Corpus Christi: Harte Research Institute for Gulf of Mexico Studies.

Yoffee, Norman. 2005. *Myths of the Archaic State: Evolution of the Earliest Cities, States and Civilisations*. Cambridge: Cambridge University Press.

Yokell, C. 2004. *Modelling Socioeconomic Evolution and Continuity in Ancient Egypt: The Value and Limitations of Zooarchaeological Analysis*. Oxford: Archaeopress.

Supplemental Material – **Pennington et al.** ***"Landscape change in the Nile Delta during the fourth millennium BC: A new perspective on the Egyptian Predynastic and Protodynastic periods"***

This supplemental material **1**) gives a brief overview of the landscape changes discussed in the text, and then outlines methods by which some data discussed in the text were established: **2**) *Changes in NPP_{pot} of the Nile Delta through time* – discussed throughout the article text and displayed on Fig. 3 – were established by assigning different ecosystem types to the different landscape types/geological units of the Nile Delta landscape model, assigning a characteristic NPP_{pot} value to each ecosystem, multiplying the areal extent of each landscape type by its NPP_{pot} value and summing across the delta area for each time period. This method is expanded upon in the relevant section below. **3**) *Changes in the zooarchaeological assemblages between different environments* (discussed in the article text) were calculated as described further below. **4**) The *locations and chronologies of prehistoric Nile Delta sites* – discussed in the article text and displayed on Figs. 2 & 3 – were compiled through an involved search of extant literature (Buchez and Midant-Reynes 2011; Chłodnicki et al. 2012; Egypt Exploration Society 2016; van Haarlem 2014; Hassan et al. 2015; Hendrickx 1999; Hendrickx and van den Brink 2002; Jucha 2011; Jucha and Maczyńska 2011; Maczyńska 2011; Mortensen 1992; Rampersad 2008; Tassie 2014; Tristant et al. 2007; 2011; von der Way 1989; van Wetering 2003; Wilson et al. 2014).

1 Overview: landscape changes

While full details of the landscape evolution discussed in the paper are presented by Pennington et al. (2017), a brief overview is given here to aid the reader. The most major landscape change discussed is the change from deltaic environments which are termed "Large-Scale Crevassing" (LSC) to environments that are named "Meandering", through the LSC-Meandering Transition (LSC-MT). These terms refer to particular behaviours that the rivers exhibited at the time; representative images of these landscapes are given in Figs. S1 and S2.

The presence of the "LSC" landscape in the Nile Delta was inferred through a reconsideration of the results of old borehole surveys (Andres and Wunderlich 1991; 1992; Krzyzaniak 1993; de Wit 1993; de Wit and van Stralen 1988; Wunderlich 1988) in the light of more recent understanding of delta evolution (Aslan and Autin 1999; Berendsen and Stouthamer 2001; Jerolmack 2009; Makaske 1998; Pennington et al. 2016), as well as the results of recent fieldwork in the Nile Delta (El-Awady 2009; El-Shahat et al. 2005; Hamdan 2003; Pennington 2019; Pennington and Thomas 2016; Rowland and Hamdan 2012; Pennington & Wilson unpublished). Pollen records were also consulted (Bernhardtet al. 2012; Hennekam et al. 2015; Leroy 1992; Saad and Sami 1967). The LSC landscape is most often represented in cores by sticky bluish-black silty-clay to clayey silt with a high percentage of organic matter. Peat layers are locally developed, and – crucially – spatial variations in grain size are rapid and unpredictable, in that units do not tend to grade into each other over wide areas. Sediments belonging to the overlying "Meandering" landscape are usually browner, often a little coarser, contain less organic matter, and display simple and predictable spatial variations in grain-size.

In the Nile Delta, the changing spatial and temporal extent of these different landscapes, as well as the dynamic location of the shoreline, the topography of the "pre-delta landscape" and the location and diminishing extent of sandy hills (gezira/turtlebacks) were mapped through an extensive review of the geological and geoarchaeological literature. New coring surveys carried out by two of the authors of the present article (Pennington, Wilson) provided further data. In total, the sedimentary logs of 1640 borehole records (Fig. **S3**) were consulted, digitised, synthesised and integrated with a database of 96 pieces of chronostratigraphic information (radiocarbon, OSL and dating information from pottery) to produce 4D stratigraphic models of the delta evolution through time.

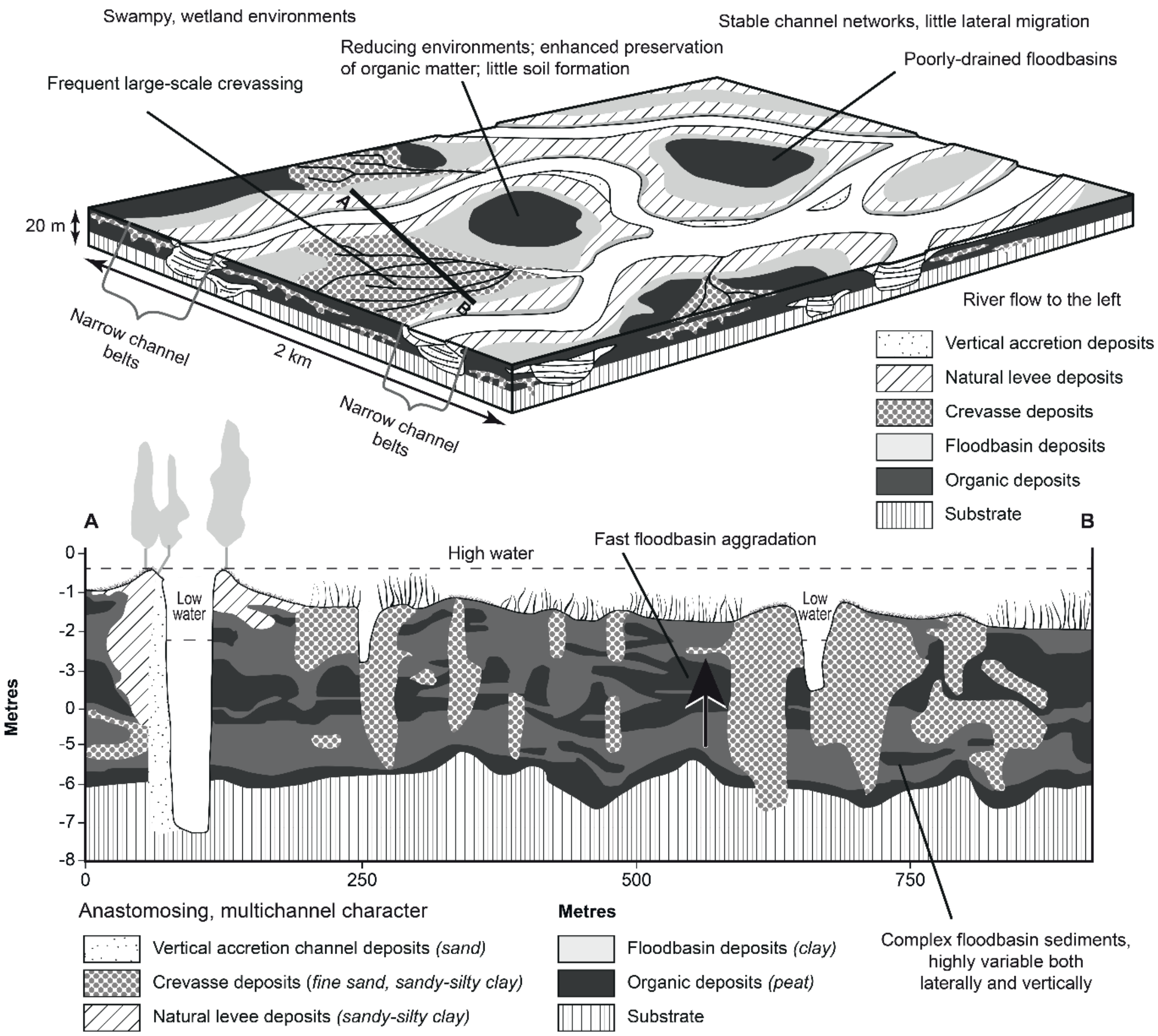

Fig. S1 Schematic of the LSC landscape, which covered much of the delta at the very start of the fourth millennium BC. Modified after Weerts (1996). This landscape would have been punctuated in many areas of the delta by "gezira" – sandy, vegetated hills standing above the level of the floodplain.

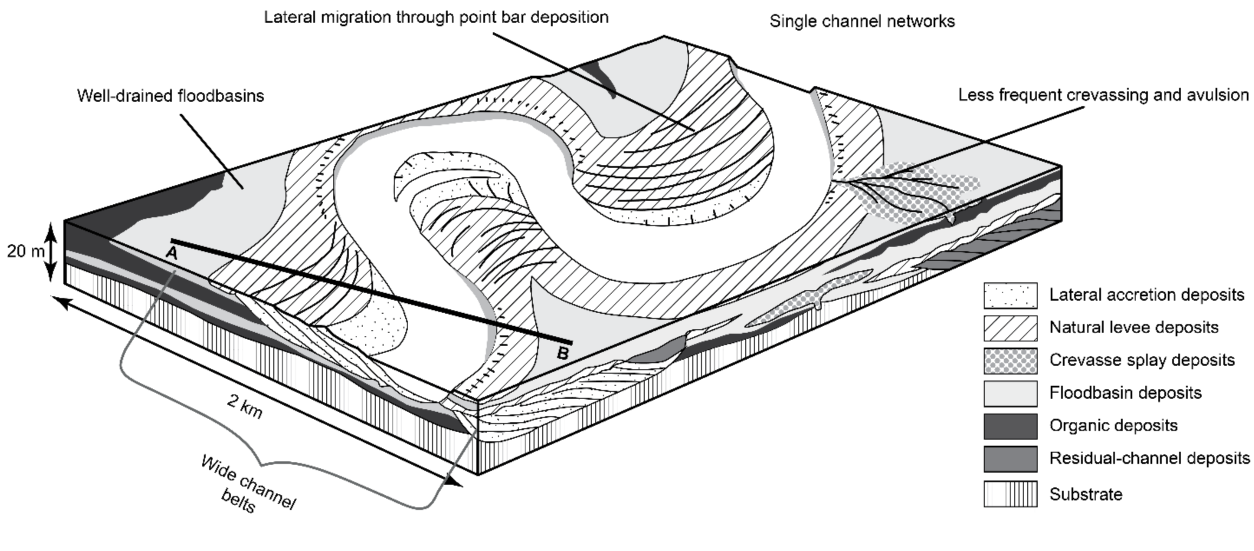

Fig. S2 Schematic of the "Meandering" landscape, which covered much of the delta in the later fourth millennium BC. Modified after Weerts (1996).

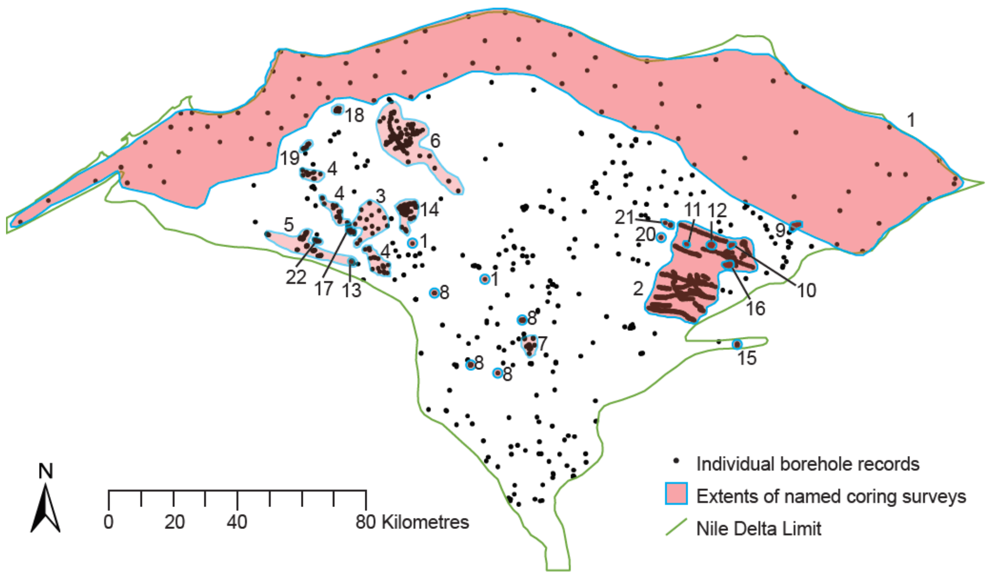

Fig. S3 Locations of cores undertaken in the Nile Delta and used in the construction of the landscape model. From Pennington et al. (2017). Labelled regions represent particular coring surveys as follows: 1) Mediterranean Basin Survey and other coring surveys in the coastal zone; 2) Amsterdam University Survey Expedition to the Nile Delta; 3) Mansoura University Western Delta Survey; 4) West Nile Delta Regional Survey; 5) Western Delta Landscape Project; 6) Buto Regional Survey; 7 & 8) Minufiyeh Archaeological Survey; 9) Minshat Abu Omar; 10) Tell Ibrahim Awad; 11) Tell Gherier; 12) Tell el-Iswid S; 13) Kom el-Hisn; 14) Sais; 15) Kafr Hassan Dawood; 16) Tell ed-Dab^{c}a; 17) Kom Geif; 18) Tell Mutubis; 19) Kom al-Ahmer/Kom Wasit; 20) Tell el-Farkha; 21) Kom el-Khilgan/Tell es-Samara; 22) Kom Firin. Most of the other cores shown were published by the Survey of Egypt. For references see Pennington et al. (2017).

2 Method: changes in NPP_{pot} of the Nile Delta through time

Changes in NPP_{pot} for the delta as a whole were established by assigning a characteristic NPP_{pot} value to each environment (geological unit) of the Nile Delta landscape model (Pennington et al. 2017), following the assumption that each environment would have harboured a particular characteristic set of ecosystems. These different ecosystems and associated NPP values were assigned as shown in Table 1 (in the article) and graphically on Fig. S4. NPP values are presented in W/m^2 assuming 1kg DM is equivalent to 20MJ and1kg C is present in 2.09kg DM (Vitousek et al. 1986; Haberl et al. 2013).

Ecosystems harboured by the landscapes represented by the Geziracover Formation in the early Holocene, as well as the “Meandering” landscapes of the Bilqas 1 Member, are assumed to be made up of grassland, woodland and shrubland, environments for which general NPP_{pot} values are known through empirical studies (Lieth and Whittaker 1975). Turtlebacks protruding above the later Holocene floodplain are assumed to host a desert and semidesert scrub ecosystem due to ongoing aridification, with a much lower NPP (Lieth and Whittaker 1975). They were not artificially irrigated, since they stood above the level of the flood and no water lifting technologies were known at this time (Mays 2010). In the coastal zone, wetlands are assumed to have been made up of brackish marshes and salt marshes, with characteristic species including *Phragmites australis*, *Scirpus maritimus*, *Cladium mariscus*, *Sarcocornia fruticosa*, *Anthrocnemum macrostachyum*; NPP_{pot} values for these ecosystems were taken as an average of measurements from within the Ebro and Mississippi deltas (Day et al. 1997; Ibañez et al. 2002). Ecosystems on the coastal sands of the barrier-beach system are assumed to be characterised by marram grass (*Ammophila*), an ecosystem for which an NPP estimate exists (Cardoch et al. 2002)[1]. Lagoonal environments and the open sea are assumed to be represented by NPP_{pot} values for "lakes and streams", and the continental shelf respectively (Lieth and Whittaker 1975). The LSC environment is assumed to be characterised by papyrus swamps, generic freshwater marshlands and swamplands, and open water. Papyrus swamps are very productive landscapes, with average NPP values of some 5.00W/m^2 (Jones et al. 2016); NPP_{pot} values for generic deltaic freshwater swamps and marshes are known from the Ebro and Mississippi, and average about 1.48W/m^2 (Day et al. 1997; Cardoch et al. 2002), while open water has a value of approx. 0.25W/m^2 (Lieth and Whittaker 1975). To provide an overall NPP_{pot} estimate for the mosaic LSC landscape represented by the LSC environment, a weighted average sum was used: papyrus swamps were assumed to cover 20% of the landscape; generic freshwater marshlands and swamps 60% and open water 20%. These percentages were estimated based on the sedimentary facies; if they are altered within reasonable bounds the same trends still hold.

The NPP_{pot} values for each landscape (Fig. S4) were multiplied by their areal extent (Fig. S5), and summed for each time period to produce an estimate of the changing total NPP_{pot} of the Nile Delta through time (Fig. S6). The resulting decrease in NPP_{pot} from 5500–2500 BC is largely attributable to the LSC-MT: the replacement of more productive LSC environments by less rich "Meandering" landscapes. The mean decrease is from 22.2–12.0GW, which would need to be compensated for by an increase in $HANPP_{harv}/NPP_{pot}$ of 1.85x in order to keep total $HANPP_{harv}$ constant.

<u>3 Method: changes in the zooarchaeological assemblages between different environments</u>

Where these terms appear in **bold** below, they should be interpreted exactly as follows:

- **Find** = A recorded fragment of an animal or derivative thereof, recorded on a NISP basis (MNI data is lacking in most instances).
- **Phase** = An individually resolved occupation phase of a particular excavated archaeological site, which can be mapped onto a date range.
- **Taxum** (**taxa**) = The organism from which a particular **find** is derived, at the highest level of taxonomic resolution recorded (e.g. *Anas sp.*/Aythyinae).
- **Edible** = A **taxum** which is known to be edible, but may or may not have been eaten.
- **Eaten** = A **taxum** which is definitely thought to have been eaten.
- **Type** = A group of closely-related **edible taxa**. See table S1 for which **taxa** are included in each **type**.
- **Set of edible eaten finds** = The total assemblage of **edible** & presumed **eaten** archaeobotanical or zooarchaeological **finds** from a particular **phase,** grouped by **type**, after excluding those **finds** which were recorded at a very crude level of taxonomic accuracy.

To investigate changes in specific resources taken from the local environment through the LSC-MT, a database of all zooarchaeological **finds** from all Neolithic to Early Dynastic Nile Delta sites was collated, and the average **set of edible eaten finds** was determined across each **phase** of every site within the "Meandering" and LSC environments. These two assemblages were taken away from each other to calculate the difference in the **set of edible eaten finds** between the LSC and "Meandering" environments, provided in Fig. S7. A comparable analysis was not undertaken for archaeobotanical remains since taphonomic issues in Egypt mean that this record does not represent human consumption patterns in any meaningful way (Thanheiser 1992; Wetterstrom and Wenke 2016).

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[1] Only aboveground NPP was provided in the reference; this was doubled to provide an estimate of total NPP (Olson et al. 2001).

Table S1. Assignment of **taxa** to **types**. Specific names in brackets are those most usually encountered within the records.

Type	**Taxa**
CLARIID	*Clarias, Heterobranchus*
PERCH	*Lates (niloticus)*
TILAPIA	*Oreochromis niloticus*
DUCK	*Anas, Aythya*
TRIONYX	*Trionyx triunguis*
PIG	*Sus scrofa*
FROG	*Rana, Bufo*
COW	*Bos primigenius*
SHEEP	*Ovis aries*
GOAT	*Capra hircus*

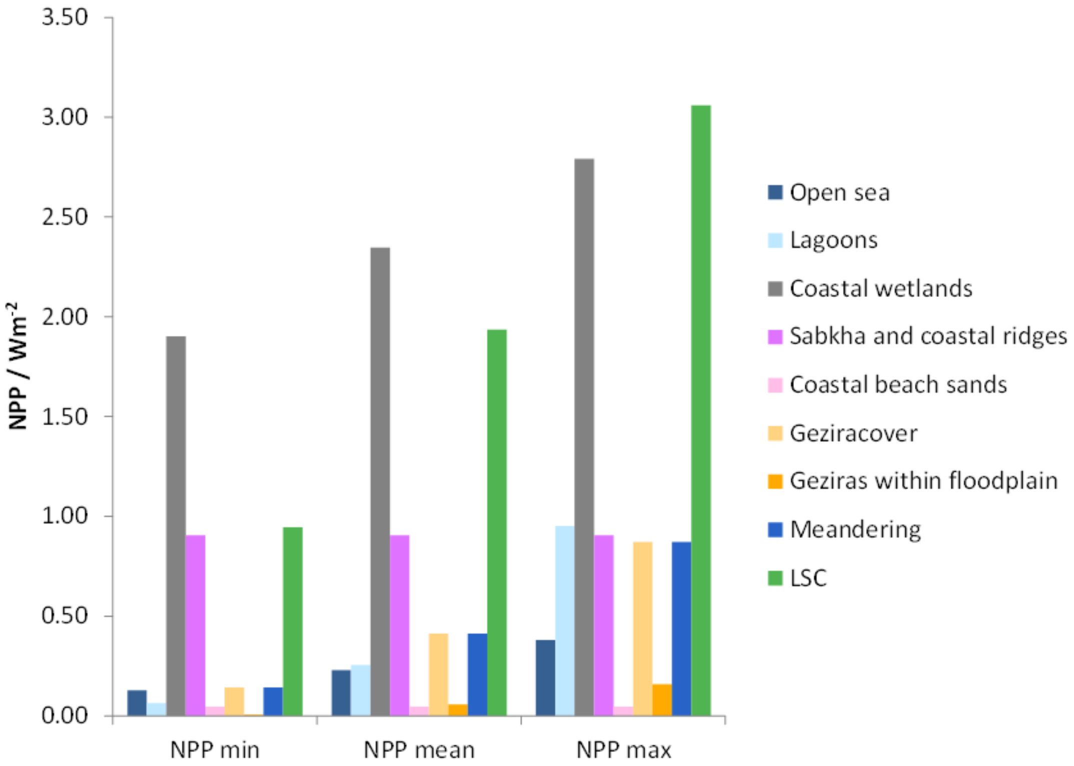

Fig. S4 Ranges and averages of suggested NPP_{pot} values for the different landscape types. See Table 1 for exact values.

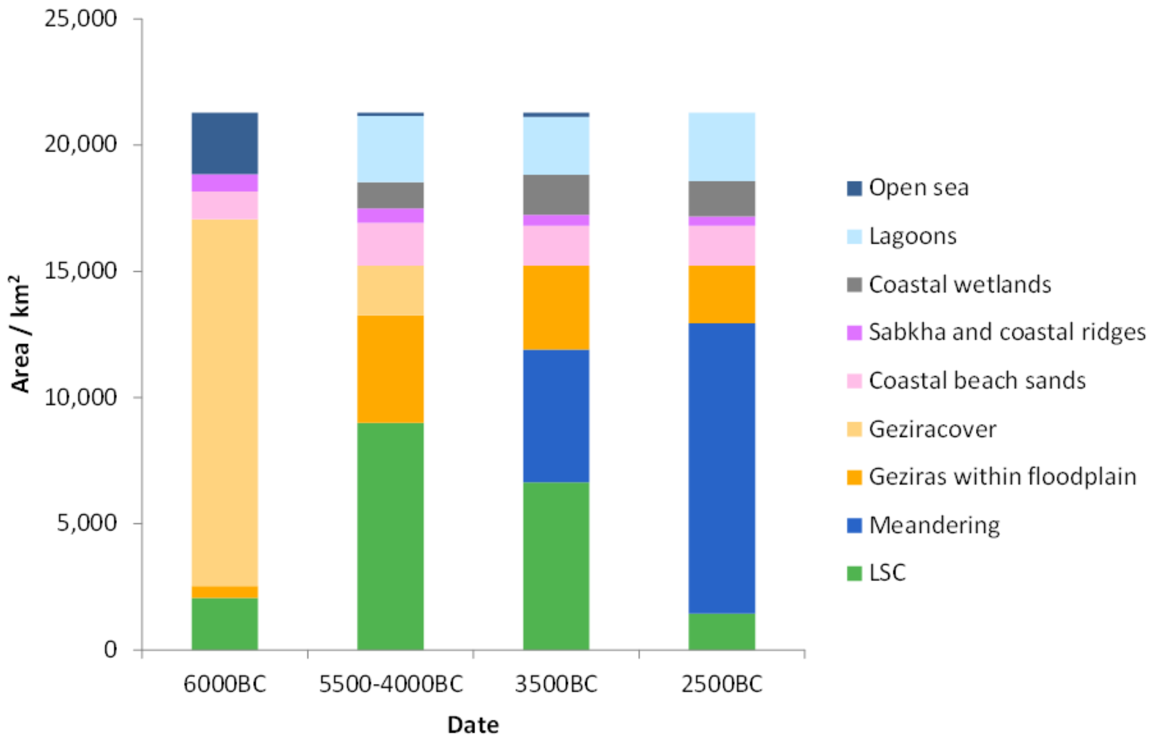

Fig. S5 Areas covered by the landscape units in the Nile Delta through time. Due to the prograding movement of the shoreline resulting in the deltaic plain being larger in the later periods than the earlier ones, an extra "landscape" type: "open sea", was created, ensuring that the same total area was being considered in each time window.

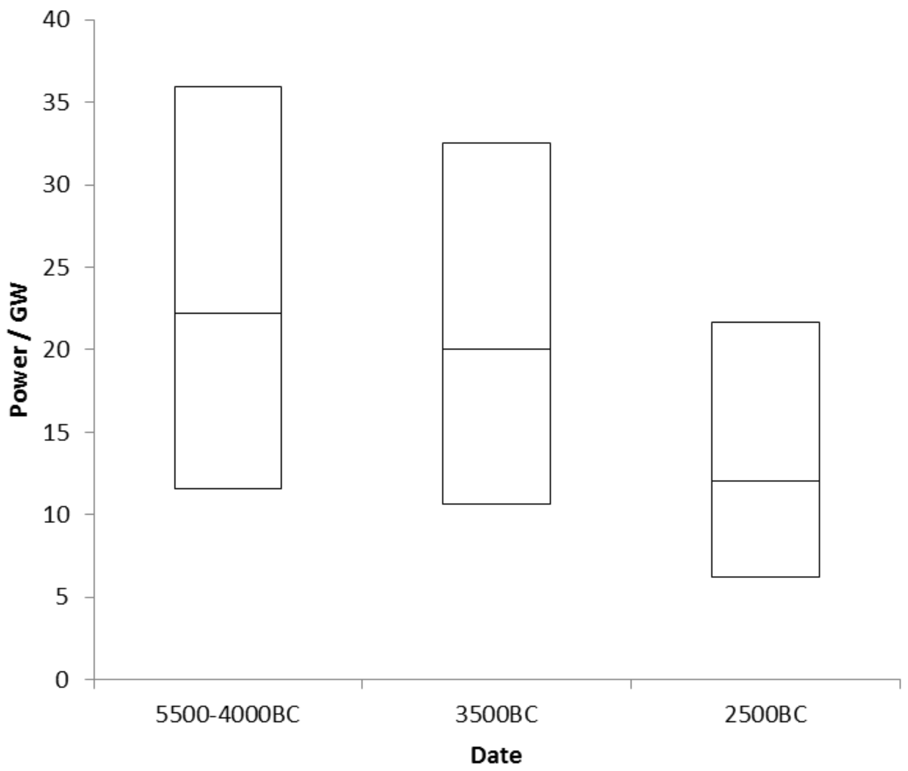

Fig. S6 Total NPP_{pot} of the Nile Delta through time. Minimum, Mean and Maximum values are shown based on the ranges given in Table S1.

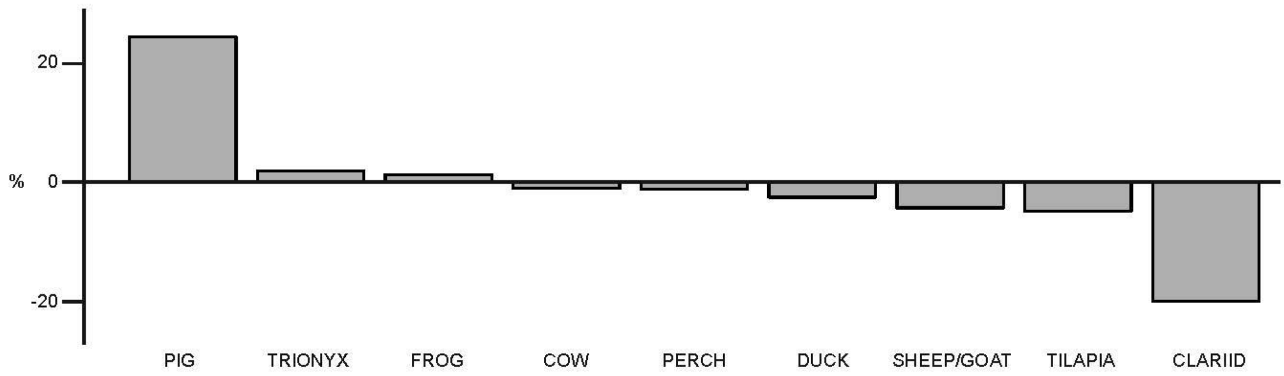

Fig. S7 Change in the **set of edible eaten finds** from sites through the LSC-MT. Only finds present at >0.1% are shown. Data from Buto, Kom el-Hisn, Mendes, Minshat Abu Omar, Sais, Tell el-Farkha, Tell el Iswid S & Tell Ibrahim Awad (Boessneck 1988; Boessneck and von den Driesch 1988; 1992; 1997; van den Brink et al. 1989; Brewer and Wenke 1992; von den Driesch 1997; Abłamowicz 2002a; 2002b; 2003; 2005; 2007; 2010; 2012; Brewer 2004; von den Driesch and Kitigawa 2007; Makowiecki 2012; van Haarlem 2014; Wilson et al. 2014).

References

Abłamowicz, R. 2002a. "Tell El-Farkha Seasons 1998-1999. Preliminary Report: Animal Bones." *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 58: 110–114.

Abłamowicz, R. 2002b. "Tell El-Farkha (Ghazala) Season 2001: Archaeozoological Research." *Polish Archaeology in the Mediterranean* 13: 123–124.

Abłamowicz, R. 2003. "Polish Excavations at Tell El-Farkha (Ghazala) in the Nile Delta. Preliminary Report 1998-2001: Animal Remains." *Archeologia Wroclaw -- Warszawa* 53 (2002): 109–114.

Abłamowicz, R. 2005. "Polish Excavations at Tell El-Farkha (Ghazala) in the Nile Delta. Preliminary Report 2002-2003: Animal Remains." *Archeologia Wroclaw -- Warszawa* 55 (2004): 70–74.

Abłamowicz, R. 2007. "Polish Excavations at Tell El-Farkha (Ghazala) in the Nile Delta. Preliminary Report 2004-2005: Archaezoological Research." *Archeologia Wroclaw -- Warszawa* 57 (2006): 109–114.

Abłamowicz, R. 2010. "Polish Excavations at Tell El-Farkha (Ghazala) in the Nile Delta. Preliminary Report 2006-2007: Archaezoological Research." *Archeologia Wroclaw -- Warszawa* 59 (2008): 143–151.

Abłamowicz, R. 2012. "Animal Remains." In *Tell El-Farkha I: Excavations 1998--2011*, edited by M Chłodnicki, K M Ciałowicz, and A Maczyńska, 409–424. Poznań: Poznań Archaeological Museum.

Andres, W, and J Wunderlich. 1991. "Late Pleistocene and Holocene Evolution of the Eastern Nile Delta and Comparisons with the Western Delta." In *Von Der Nordsee Bis Zum Indischen Ozean*, edited by H. Brückner and U. Radtke, 121–130. Stuttgart: Steiner.

Andres, W, and J Wunderlich. 1992. “Environmental Conditions for Early Settlement at Minshat Abu Omar, Eastern Nile Delta, Egypt.” In *The Nile Delta in Transition: 4th--3rd Millennium BC*, edited by E C M van den Brink, 157–166. Tel Aviv: IES.

Aslan, A, and W J Autin. 1999. “Evolution of the Holocene Mississippi River Floodplain, Ferriday, Louisiana: Insights on the Origin of Fine-Grained Floodplains.” *Journal of Sedimentary Research* 69 (4): 800–815.

Berendsen, H J A, and E Stouthamer. 2001. *Paleogeographic Development of the Rhine-Meuse Delta, The Netherlands*. Assen: Van Gorcum.

Bernhardt, C E, B P Horton, and D J Stanley. 2012. “Nile Delta Vegetation Response to Holocene Climate Variability.” *Geology* 10 (7): 615–618.

Boessneck, J. 1988. “Tierknochenfunde Aus Der Spätzeit (6-4 Jh. V. Chr.) Aus Minshat Abu Omar (Ägypten).” *Fontes Archaeologici Posnanienses* 36: 217–220.

Boessneck, J, and A von den Driesch. 1988. “Tierknochenfunde Vom Tell Ibrahim Awad Im Ostlichen Nildelta.” In *The Archaeology of the Nile Delta: Problems and Priorities*, edited by E C M van den Brink, 117–122. Amsterdam: Netherlands Foundation for Archaeological Research in Egypt.

Boessneck, J, and A von den Driesch. 1992. “Weitere Tierknochenfunde Vom Tell Ibrahim Awad Im Östlichen Nildelta.” In *The Nile Delta in Transition: 4th--3rd Millennium BC*, edited by E C M van den Brink, 97–110. Tel Aviv: IES.

Boessneck, J, and A von den Driesch. 1997. “Tierknochenfunde.” In *Tell El Fara’in -- Buto I*, edited by T Von der Way, 206–216. Mainz: Archäologische Veröffentlichungen Deutsches Archäologisches Institut Kairo.

Brewer, D J. 2004. “Faunal Remains.” In *Excavations at Mendes Vol 1: The Royal Necropolis*, edited by D B Redford, 202–210. Leiden: Koninklijke Brill.

Brewer, Douglas J, and Robert J Wenke. 1992. “Transitional Late Predynastic-Early Dynastic Occupations at Mendes: A Preliminary Report.” In *The Nile Delta in Transition: 4th--3rd Millennium BC*, edited by E C M van den Brink, 191–198. Tel Aviv: IES.

Buchez, N, and B Midant-Reynes. 2011. “A Tale of Two Funerary Traditions: The Predynastic Cemetery at Kom El-Khilgan (Eastern Delta).” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt’’*, edited by R Friedman and P N Fiske, 831–858. Leuven: Peeters.

Cardoch, L, J W Day, and C Ibañez. 2002. “Net Primary Productivity as an Indicator of Sustainability in the Ebro and Mississippi Deltas.” *Ecological Applications* 12 (4): 1044–1055.

Chłodnicki, M, K M Ciałowicz, and A Maczyńska. 2012. *Tell El-Farkha I: Excavations 1998--2011*. Poznań: Poznań Archaeological Museum.

Day, J W, J F Martin, L Cardoch, and P H Templet. 1997. “System Functioning as a Basis for Sustainable Management of Deltaic Ecosystems.” *Coastal Management* 25 (2). Taylor & Francis: 115–153. doi:10.1080/08920759709362315.

de Wit, H E, and L van Stralen. 1988. *Geo-Archaeology and Ancient Distributaries in the Eastern Nile Delta: Results of the 1987 AUSE Survey in Sharqiya, Egypt*. Amsterdam.

de Wit, H E. 1993. “The Evolution of the Eastern Nile Delta as a Factor in the Development of Human Culture.” In *Environmental Change and Human Culture in the Nile Basin and Northern Africa until the 2nd Millennium B.C.*, edited by L Krzyzaniak, M Kobusiewicz, and J Alexander, 305–320. Poznań: Poznań Archaeological Museum.

Egypt Exploration Society. 2016. “The Egypt Exploration Society Delta Survey: An Information Centre for the Archaeological Sites of Lower Egypt. Http://Deltasurvey.Ees.Ac.Uk/Ds-Home.Html (Last Accessed February 2017).”

El-Awady, H M S. 2009. *Application of the Geophysical Survey for Environmental and Archaeological Purposes, Central Western Part of the Nile Delta, Egypt*. University of Mansoura: Unpublished MSc Thesis.

El-Shahat, A, H Ghazala, P Wilson, and Z Belal. 2005. “Lithofacies of the Upper Quaternary Sequence of Sa El-Hagar Area, Gharbiya Governorate, Nile Delta, Egypt.” *Mansoura Journal of Geology & Geophysics* 32: 97–120.

Haberl, H, K H Erb, and F Krausmann. 2013. “Global Human Appropriation of Net Primary Production (HANPP). Http://Www.Eoearth.Org/View/Article/153031 (Last Accessed February 2017).” *The Encyclopedia of Earth*.

Hamdan, M A. 2003. “Late Quaternary Geology and Geoarchaeology of Kafr Hassan Dawood, East Delta.” In *Egyptology at the Dawn of the Twenty-First Century: Proceedings of the Eighth International Congress of Egyptologists, Cairo, 2000*, edited by Z Hawass and L Pinch Brock, 1:221–228. Cairo: The American University in Cairo Press.

Hassan, F A, G J Tassie, T Rehren, and J Van Wetering. 2015. “On-Going Investigations at the Predynastic to Early Dynastic Site of Kafr Hassan Dawood: Copper, Exchange and Tephra.” *Archéo-Nil* 25: 75–90.

Hendrickx, S. 1999. “La Chronologie de La Préhistoire Tardive et Des Débuts de l’histoire de l’Égypte.” *Archéo-Nil* 9: 13–81.

Hendrickx, S, and E C M van den Brink. 2002. “Inventory of Predynastic and Early Dynastic Cemetery and Settlement Sites in the Egyptian Nile Valley.” In *Egypt and the Levant: Interrelations from the 4th through the Early 3rd Millennium BCE*, edited by E C M van den Brink and T E Levy, 346–398. London: Leicester University Press.

Hennekam, R, T H Donders, K Zwiep, and G J de Lange. 2015. “Integral View of Holocene Precipitation and Vegetation Changes in the Nile Catchment Area as Inferred from Its Delta Sediments.” *Quaternary Science Reviews* 130: 189–199.

Ibañez, C, A Curco, J W Day, and N Prat. 2002. “Structure and Productivity of Microtidal Mediterranean Coastal Marshes.” In *Concepts and Controversies in Tidal Marsh Ecology*, edited by M P Weinstein and D A Kreeger, 107–136. New York: Kluwer Academic Publishers.

Jerolmack, D J. 2009. “Conceptual Framework for Assessing the Response of Delta Channel Networks to Holocene Sea Level Rise.” *Quaternary Science Reviews* 28 (17–18): 1786–1800.

Jones, M B, F Kansiime, and M J Saunders. 2016. “The Potential Use of Papyrus (Cyperus Papyrus L.) Wetlands as a Source of Biomass Energy for Sub-Saharan Africa.” *Global Change Biology: Bioenergy*, 1–8.

Jucha, M. 2011. “Tell Abu El-Halyat: The New Naqada III -- Old Kingdom (?) Site in the Northeastern Nile Delta.” *Studies in Ancient Art and Civilization* 15: 65–76.

Jucha, M, and A Maczyńska. 2011. “Settlement Sites in the Nile Delta.” *Archéo-Nil* 21: 33–50.

Krzyzaniak, L. 1993. “New Data on the Late Prehistoric Settlement at Minshat Abu Omar (Eastern Nile Delta).” In *Environmental Change and Human Culture in the Nile Basin and Northern Africa until the 2nd Millennium B.C.*, edited by L Krzyzaniak, M Kobusiewicz, and J Alexander, 321–325. Poznań: Poznań Archaeological Museum.

Leroy, S A G. 1992. “Palynological Evidence of Azolla Nilotica Dec. in Recent Holocene of the Eastern Nile Delta and Palaeoenvironment.” *Vegetation History and Archaeobotany* 1 (1): 43–52.

Lieth, H, and R H Whittaker. 1975. *Primary Productivity of the Biosphere*. Berlin: Springer-Verlag.

Maczyńska, A. 2011. “The Lower Egyptian-Naqada Transition: A View from Tell El-Farkha.” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 879–908. Leuven: Peeters.

Makaske, B. 1998. “Anastomosing Rivers: Forms, Processes and Sediments.” Universiteit Utrecht.

Makowiecki, D. 2012. “Fish Remains.” In *Tell El-Farkha I: Excavations 1998--2011*, edited by M Chłodnicki, K M Ciałowicz, and A Maczyńska, 425–430. Poznań: Poznań Archaeological Museum.

Mays, L W. 2010. “Water Technology in Ancient Egypt.” In *Ancient Water Technologies*, edited by L W Mays, 53–65. Dordrecht: Springer.

Mortensen, B. 1992. “Carbon-14 Dates from El-Omari.” In *The Followers of Horus: Studies in Honour of Michael Allen Hoffman*, edited by R. Friedman and B. Adams, 173–174. Oxford: Oxbow Books.

Olson, R J, K R Johnson, D L Zheng, and J M O Scurlock. 2001. *Global and Regional Ecosystem Modelling: Databases of Model Drivers and Validation Measurements*. Oak Ridge: Oak Ridge National Laboratory Environmental Sciences Division.

Pennington, B T. 2019. “Palaeoenvironments of the Northwest Nile Delta: The Ancient Landscape Context of Kom Al-Ahmer and Kom Wasit.” In *Kom Al-Ahmer/Kom Wasit I*, edited by M Kenawi, 56–66. Oxford: Archaeopress.

Pennington, B T, J M Bunbury, and N Hovius. 2016. “Emergence of Civilisation, Changes in Fluvio-Deltaic Styles and Nutrient Redistribution Forced by Holocene Sea-Level Rise.” *Geoarchaeology* 31 (3): 194–210.

Pennington, B T, F Sturt, P Wilson, J Rowland, and A G Brown. 2017. “The Fluvial Evolution of the Holocene Nile Delta.” *Quaternary Science Reviews* 170: 212–231.

Pennington, B T, and R I Thomas. 2016. “Paleoenvironmental Surveys at Naukratis and the Canopic Branch of the Nile.” *Journal of Archaeological Science: Reports* 7: 180–188. doi:10.1016/j.jasrep.2016.03.053.

Rampersad, S. 2008. “Introducing Tell Gabbara: New Evidence for Early Dynastic Settlement in the Eastern Delta.” *Journal of Egyptian Archaeology* 94: 95–106.

Rowland, J M, and M A Hamdan. 2012. “The Holocene Evolution of the Quesna Turtle-Back: Geological Evolution and Archaeological Relationships within the Nile Delta.” In *Prehistory of Northeastern Africa: New Ideas and Discoveries.*, edited by J Kabaciński, M Chłodnicki, and M Kobusiewicz, 11–24. Poznań: Poznań Archaeological Museum.

Saad, S I, and S Sami. 1967. “Studies of Pollen and Spores Content of Nile Delta Deposits (Berenbal Region).” *Pollen et Spores* 9 (3): 467–503.

Tassie, G J. 2014. *Prehistoric Egypt: Socioeconomic Transformations in North-East Africa from the Last Glacial Maximum to the Neolithic, 24,000-4,000BC*. London: Golden House Publications.

Thanheiser, U. 1992. “Plant-Food at Tell Ibrahim Awad: Preliminary Report.” In *The Nile Delta in Transition: 4th--3rd Millennium BC*, edited by E C M van den Brink, 117–121. Tel Aviv: IES.

Tristant, Y, M De Dapper, S Aussel, and B Midant-Reynes. 2011. “Cultural and Natural Environment in the Eastern Nile Delta: A Geoarchaeological Project at Tell El-Iswid (Nile Delta).” In *Egypt at Its Origins 3: Proceedings of the Third Conference ``Origin of the State. Predynastic and Early Dynastic Egypt''*, edited by R Friedman and P N Fiske, 171–173. Leuven: Peeters.

Tristant, Y, M De Dapper, and B Midant-Reynes. 2007. “Recherches Géo-Archéologiques Sur Le Site Pré- et Protodynastique de Kôm El-Khilgan (Delta Du Nil): Résultats Préliminaires Des Campagnes de Prospection 2002-2004.” In *Proceedings of the Ninth International Congress of Egyptologists*, edited by J C Goyon, C Cardin, J F Garrel, and G Zaki, 2:1841–1850. Leuven: Peeters.

van den Brink, E C M, K Schmidt, J Boessneck, A von den Driesch, and G J de Roller. 1989. “A Transitional Late Predynastic -- Early Dynastic Settlement Site in the Northern Nile Delta, Egypt.” *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 45: 55–108.

van Haarlem, W M. 2014. “Temple Deposits in Early Dynastic Egypt: The Case of Tell Ibrahim Awad.” Leiden Universiteit.

van Wetering, J. 2003. “Map of the Nile Delta c. 3000BC Showing the Settlement Patterning of the Major Predynastic to Early Dynastic Sites. Http://Www.e-c-h-o.Org/Khd/Location.Html (Last Accessed February 2017).”

Vitousek, P M, P R Ehrlich, A Ehrlich, and P A Matson. 1986. “Human Appropriation of the Products of Photosynthesis.” *Bioscience* 36 (6): 363–373.

von den Driesch, A. 1997. “Tierreste Aus Buto Im Nildelta.” *Archaeofauna* 6: 23–39.

von den Driesch, A, and C Kitigawa. 2007. “Untersuchung Der Tierknochenfunde.” *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 63: 152–159.

von der Way, T. 1989. “Tell El-Fara’in -- Buto. 4. Bericht.” *Mitteilungen Des Deutschen Archäologischen Instituts. Abteilung Kairo* 47: 275–308.

Weerts, H J T. 1996. “Complex Confining Layers: Architecture and Hydraulic Properties of Holocene and Late Weichselian Deposits in the Fluvial Rhine-Meuse Delta, The Netherlands.” Universiteit Utrecht.

Wetterstrom, W, and R J Wenke. 2016. “Kom El-Hisn’s Plant Remains.” In *Kom El-Hisn (ca. 2500 -- 1900 BC): An Ancient Settlement in the Nile Delta of Egypt*, edited by R J Wenke, R W Redding, and A J Cagle, 205–254. Atlanta: Lockwood Press.

Wilson, P, G Gilbert, and G Tassie. 2014. *Sais II: The Prehistoric Period*. London: Egypt Exploration Society.

Wunderlich, J. 1988. “Investigations on the Development of the Western Nile Delta in Holocene Times.” In *The Archaeology of the Nile Delta: Problems and Priorities*, edited by E C M van den Brink, 251–257. Amsterdam: Netherlands Foundation for Archaeological Research in Egypt.