

A River in Drought: Consequences of a Low Nile at the End of the Old Kingdom

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Abstract It is thought that a significant factor in the fall of the Egyptian Old Kingdom was the occurrence of a number of lower than average inundation events that led to a decline in agricultural output, causing a famine that undermined the authority of the government. However, very little consideration has been given to how a lesser volume of water may have impacted upon the Nile itself. This composition investigates the potential for ecological change that may have developed as a consequence of a lower river. Since a lower river exhibits less force, its physical properties should change, which would in turn alter the chemical and biological factors that are expressed. A low Nile should therefore have resulted in changes to the distribution and abundance of plant life along the river. Four plants characteristic to Pharaonic times were investigated to see how they may have responded. Papyrus and Phragmites are suggested as plants that would benefit from a situation where the nutrients remained within the river, whereas Typha and Lotus display characteristic that benefit less when the river retains nutrients that would have normally been lost to the surrounding landscape.

Keywords Ancient Egypt, Nile, Drought, Environmental Response, Climate Change

1. Introduction

The ending of the Holocene Wet phase resulted in the dislocation of many communities around Anatolia and the Middle East: with these climatic events being linked to the decline of the first urban centers in the Levant [1][2][3][4], the fall of the Akkadian Empire [5] and the deterioration of the Palatial Culture of the Mediterranean islands [6][7]. They are thought to have also brought about the fall of the Old Kingdom [8][9]; during which time, Egypt experienced a number of drought-like episodes [9]; with the land experiencing long-term famine [10][11][12][13]. The calamity impacted upon the stability of the society as a whole [14][15], and in connection with a weakened government [16][17], has been suggested as a direct causal link to the fall of the Old Kingdom [5][14][15]. This crisis

in food supply; affected Egyptian society in a debilitating manner, and the developing societal unrest that began at the end of the Sixth Dynasty and lasted throughout the First Intermediate Period [10][11][12][13][18][19] led to a so-called “dark age” in Egyptian history [2][12][20]. The cultural developments that occurred at this time have been linked to the environmental situations experienced [21][22][23].

Historically, the Nile ‘flood’ delivered vast amounts of silt to the land with its annual inundation, the volume of nutrients influencing the diversity of food webs that developed along the waterway [4][11][12][24][25]. Notwithstanding the river was a vital factor in ensuring prosperity for the civilization [1], none have asked the fundamental question... *What happened to the River when the land was in drought?* Despite drought seeming a more common occurrence [1], very little commentary exists discussing the conditions experienced by the river during this time. When Egyptologists talk about ‘drought’, it is with regard to the impact upon agriculture: meaning that the level of inundation as less than normal. If Ancient Egypt experienced a ‘drought’ at this time, then it is in regard to a lower-than-normal river and this change must have impacted upon the river as well.

The thinking follows as such...

1. A lower river implies the inundation carries less water.
2. Consequently, fewer nutrients are deposited onto the land.
3. A greater amount of nutrients remains in the river.
4. This would change the environmental conditions of the river, and subsequently.
5. The surrounding ecosystems should have experienced some change.

2. Applying Ecological Principles to the Past

Riverine Ecosystems

In Egypt, the ecosystem types can be broadly divided into Delta, Riverine, Oasis and Desert [34][35][36].

Ecosystems consist of various components [26]; the different physical and chemical properties they exhibit, as well as biological factors that encompass the living things within that environment [27]. All the individual food chains in an area can be represented by a more complex food web [25]. Changing physical and chemical characteristics of an ecosystem also impact upon the biology of that ecosystem [24][25]. In the a natural state, these ecosystem interactions are in a form of dynamic equilibrium, with the system cycling through regular patterns, leading to ecosystems generally presenting overall characteristics that are unique to themselves [28][30][31][32]. In times of irregular or unnatural water flow, this system is knocked out of balance, with changes to one component within a food web leading to ramifications for the entire food web [33]. The application of simple ecological principles to situation the example of a weakening Nile could suggest some consequences that could have arisen.

Egypt is the Nile

The hydrology of Egypt is unique because all of the water that flows through the country comes from external sources [1]. Ancient Egypt has been described as a “Hydraulic Society” [37], its civilization developing as a direct consequence of the large-scale manipulation of water. The relationship between ancient Egyptians and the Nile River was instrumental in the commencement of and fundamental to the long-term survival of that civilization [34][39]. Without the benefits of alluvial deposits from the flood, the capability and productive capacity of the land would be severely diminished [4] [11] [12] [35] [41]. It is difficult to envisage the development of the complex ancient Egyptian civilization without the adoption of irrigation [34] [37] [43] [45] [46]. In relating the geo-archaeological history of the region, it should also be possible to relate the cultural history of a region to its environmental history [5][38][40][42][44].

A River in “Drought”

Because riverine ecosystems, such as the Nile have water flowing in one direction only [31][47], the physical, chemical and biological factors that the river displays usually differ along its length [31][47][48], as does the characteristics they exhibit [49][50]. Along its length, specialized microhabitats develop, leading to a distinctive ecology containing organisms adapted to those situations [48]. Rapid environmental change, one that is unusually long in duration or exceptionally severe, would have resulted in uncharacteristic environmental responses [51][52][53]. If the system was disturbed for periods of time longer than seasonal, or where the circumstances changed more significantly than normal, the physical and chemical characteristics of the river would become abnormal and would have an impact upon the biological

populations existing within the waterway [54][55].

In our cultural exemplar, a drought is what happens to the land; as “...a *prolonged period of abnormally low rainfall, leading to water shortage...*” [56]. When relating this to the Nile, a ‘regular’ flood resulted in nutrients spilling over onto the nearby land. Rzóska [30], described the inundation in terms of the land “*stealing nutrients*” from the river. In Nilotic terms, nutrients are lost during an inundation [1]; if an inundation did not occur, leading to a ‘low’ Nile, then those would have remained in the river [57]. The retention of these nutrients within the river would have resulted in changes to the biological and chemical nature of the river.

Flow Rates Determine Habitat and Biodiversity

In modern situations, the alteration of flow regimes is often claimed to be the most serious and continuing threat to ecological sustainability of rivers and their associated floodplain wetlands [59][60]. When the volume of water was not enough to initiate an inundation, then the potential for the water to change the landscape would also have diminished, changing the physical characteristics of the ecosystem [58].

In case of a drought, the overall volume of water available for the ecosystem has lessened, diminishing the potential momentum of the stream, reducing the energy value of the water current [47][61]. Bunn and Arthington [62] clarified the basic principles outlining the consequences of a minimal flow in a river. These can be paraphrased in the following manner...

Principle 1: Flow is a major determinant of physical habitat in streams, which in turn is a major determinant of biotic composition. This physical habitat in turn influences the distribution and abundance of aquatic organisms.

Principle 2: Aquatic species have evolved life history strategies primarily in direct response to the natural flow regimes. Alteration to the natural flow regimes can lead to a loss of biodiversity of native species.

Principle 3: Maintenance of natural patterns of connectivity is essential to the viability of populations of many riverine species. Species survival diminishes when these populations become isolated.

Principle 4: The invasion and success of exotic and introduced species in rivers is facilitated by the alterations to the normal flow regimes.

These doctrines suggest that, as a system becomes less normal or more irregular, the biological profile of the ecosystem under investigation changes to one that is less archetypal. Changes to the regular cycles associated with a river impact upon the biodiversity present. Some parts of a river are naturally deeper than others [61], so there already exists different environmental characteristics within the

habitat [25][50]. As the flow rates diminish or change, these differences become more pronounced, and the effects more exaggerated [47] [50].

Erosion

A water flow with less energy results in decreased erosive force. The stability of the soil strata is affected by the energy of the water that is flowing across it [63]. With less power comes less erosive ability and a weakening of the river's ability to break up clumps of matter that can encumber the river. It would also allow plants growing alongside the river on its banks to develop greater purchase. The power of the water affects the rate of erosion, thus impacting upon the width of the marshes [64]. A weaker than usual river would result in a smaller volume of flowing water, suggesting that a commensurate decrease in the rate of erosion should occur [65]. Sometimes, along the length of a river, secondary channels form where the river did not have enough strength to force its way back to the main flow [66][67]. During times of a low Nile more numerous secondary channels would develop. It is expected that the number of secondary channels should increase because water with less energy is forced to divert its passage when it encounters a blockage, rather than driving its way through [66][67]. Because of the restricted flow, it would be expected that they were shallower.

Sediment Transport and Nutrient Supply

The power of the river determines how much sediment it can carry as well as determining how far these sediments can be carried [47][48]. If a river is experiencing less flow or volume or power than normal, then the distribution of its sediments is different to what would happen typically changing the effect on the riverbed and surrounding floodplains. As a river begins to progressively slow, the largest particles settle out first since those particles which would normally be transported by the energetic water settle out more rapidly [61]. Smaller particles would not remain suspended for as long, nor travel as far as usual. The lightest particles remain suspended for the longest times.

Since less material is delivered to the land, more of it settles within the environs of the river, leaving less available for cultivation, resulting in a downturn in agricultural productivity [69][70]. The reported sediment decreases, and subsequent fertility decline in northern Egypt since the construction of the Aswan dam being a modern example of this phenomenon [41][71]. For the historical era, Krom et al., [29] have shown that a flowing Nile produced a consistent deposit of sediment into the Mediterranean, the lesser the water flow, the closer to the mouth were the deposits and the greater variety of nutrients were present.

With a weaker flow, the "cleansing" activity of the river would be weakened, not being able to "flush" itself as well

as a stronger river, so organic remains linger in the waterway for a longer time [57][72], allowing for a rapid increase in biological material [67][72]. As this material decomposes, the amount of oxygen within the water diminishes, leading to eutrophication [48][72]. The longer the nutrients remain in the river, the more oxygen is lost [72]. As a river slows, the ability to absorb oxygen from the atmosphere decreases [47], this also lessens the amount of oxygen available to aquatic organisms residing within. The amount of oxygen and carbon dioxide present influences the acidity of the waterway. Salinity changes impact upon oxygen solubility, also changing the chemical nature of the water.

The change in nutrient content and composition affects the biological nature of the waterway [47][50], altering the acidity of the waterway, resulting in changes to the chemical properties of the waterway. Because of increasing biological pollution, the acidity of a waterway begins to alter [73]. Changes of acidity within a waterway impacts upon the solubility of many substances within the waterway as well as interfering with the life cycles of many organisms living in the water [25][48][74][75].

A series of long-term, non-flood events would impact upon those organisms that have adapted to a more drenched situation. If a system that is consistently flooded experiences drought, then the overall productivity of the primary producers declines due to a smaller-than-average water and nutrient supply [68].

Turbidity Effects

Rivers with a weaker than normal flow are less agitated and less turbid, so are more likely to be clear [76], because even the finer particles they carry remain suspended for a shorter amount of time than normal [77]. Due to less mixing of materials moving at a more sedate less energetic pace, differences in the appearance of the water will become more contrasted as distinct layers would develop, implying that light would be able to penetrate more deeply [77] and improve the potential for an increase in photosynthetic activity [25][47]. However, a wider photosynthetic zone can lead to an increase in the growth of algae and other microscopic plants, which rapidly make the waterway much cloudier, negating this change, further increasing the temperature gradient differences [25][72]. This growth also impacts upon the wider food web within the habitat [72][76]. Within the secondary channels, the water flow would be slower than that experienced by the rest of the river [25]. Secondary channels would experience the same changes in turbidity and algal growth as described previously, only at a faster scale [25][78].

Temperature Changes and Evaporations Rates

As the river became slower and shallower, its capacity to absorb solar radiation increases [25], heating the top layer

more readily, so the surface develops a temperature warmer than usual [25]. A weaker river results in less mixing of water, so the waterway develops larger temperature gradients between the surface and depths compared to the typical situation [25][76]. Many species require specific temperature ranges for their various metabolic functions [25], leading to variances in local populations [81][82]. Warmer rivers experience greater rates of evaporation, leading to an increase in the salinity level of the waterway [25]. The shallower areas become warmer than those deeper areas, and with more secondary channels developing, the differences in salinity levels between different parts of the river becomes more amplified and the consequences more significant [79]. Many riverine organisms respond poorly to rapid changes in the salinity level [50][80].

Warm water dissolves less oxygen than does cold, so a warming river contains less oxygen available for its inhabitants [25][66], further exacerbating the differences between secondary channels and the major branches. The amount of oxygen available for organisms living below the surface layer is diminished [25]. As the amount of dissolved oxygen drops below normal levels in water bodies, it impacts upon the normal functioning of the micro-organisms present, altering the pre-existing food cycles and changing the population dynamics within that habitat [76][82]. Some organisms die off due to oxygen loss [25], their decomposition adds to the nutrient volume in the river and further reducing the amount of oxygen available in the water [25]. Similarly, the ability of water to dissolve carbon dioxide is affected by changes to temperature [25][47]. This is one factor that helps determine the acidity of the waterway [25], causing it to depart from the natural level of acidity developed over many years of adaptation [74].

3. Effects on Riverine Food Webs

While these environmental factors have been identified, and commented upon individually, they can and do influence one another: physical, chemical and biological factors are in a state of unceasing interaction. Within a weakening river, as the temperature, acidity and salinity levels change, the biological profile of the river begins to change. As the environmental factors alter, the biological profile of the river would be constantly shifting. The river retains its suspended nutrients if an inundation does not occur; when the nutrients remain in the river, the organic base should develop more rapidly. A habitat's food web is built up by combining all the individual food chains together; and this is affected by the availability of nutrients [47][50][54]. In circumstances of environmental change, as the nutrient balance shifts, the proportion of species that made up the initial food web alters [66]: the phenomenon of nutrient-rich waterways changing the natural ecology

recorded in the modern Nile [67][68].

Implications for Nile Food Webs

By applying basic ecological principles and utilizing current research and experience from places experiencing similar circumstances in modern times, it is possible to suggest the responses of some organism [84][85] and infer changes to Nilotic organisms that would develop in these situations. The interactions that take place do so under different base line conditions to the normal situation. Some areas within the waterway can become oxygen depleted as nutrient build-up, with its commensurate increase in biological pollution, encourages the development of anaerobic conditions within the waterway causing eutrophication [78]. Micro-organisms such as blue-green algae begin to flourish, clogging the waterways [78][83]. As the balance of nutrients changes, some life cycles become more difficult and others easier, with the number of scavenger and decomposer organisms increasing due to greater mortality rates among oxygen breathers. Generally, it is observed that the food webs in disturbed habitats change in structure and composition [77][83], with organisms not able to adapt or respond to these new conditions dying out or moving away [78][86]. Thienemann [87] elucidated the basic principles of an ecosystem responding to a changing ecological situation: his "Basic Principles" may be summarized as follows...

Principle 1: The greater the diversity of conditions in a habitat, the greater the variety of species in that habitat.

Principle 2: The more the conditions deviate from the normal, the smaller the variety of species and the greater the numbers of these individual species becomes.

Principle 3: The longer a habitat has been in the same condition, the richer and more varied the species in the habitat, and the more stable that habitat is.

As the variability of the habitat increases so should the biodiversity [88]. Therefore, the reverse principle should readily apply, as the circumstances stray from the "normal" situation, it is expected that some species would flourish and another flounder. An unreliable, sometime non-existent, inundation was different to the normal situation and not a circumstance to which most inhabitants of the habitat had become adapted.

Aquatic Plants and their Response to Drought

Aquatic plants need two essential nutrients to grow: nitrogen and phosphorus. In circumstances of environmental change, as the nutrient balance shifts, the interactions that take place do so under different base line conditions to normal, so the assortment of species that

made up the original food web would alter [66]. Some respond more effectively than others [89]. Some, for example, may be able to tolerate increasingly saline solutions, others not. Some may tolerate increasingly acidic waterways, whereas other may experience hardship [90][91].

Zahran and Willis [71] have classified the ancient vegetative landforms into seven basic “vegetation groups”. Plants identified as historically significant to fresh water and reed-swamp habitats include the most common “reeds”; *Phragmites australis* and *Typha domingensis* (cattails); *Cyperus Papyrus* and the two ‘lotuses’ (more properly water lilies?) [92][93], the White (*Nymphaea lotus*) and the Blue (*Nymphaea caerulea*), as the most important waterway plants.

4. Papyrus and a River in Drought

The simple Papyrus plant, *Cyperus Papyrus*, found commonly in the archaeological record [71][89][95], especially in the marshland regions [96], is almost unknown in the modern vegetative profile of Egypt [97]. Papyrus is a large, emergent, aquatic perennial, producing short rhizomes, whose tough roots can extend 1 meter or more into the soil, whose erect culms can grow up to 5 meters tall [98]. The *Cyperus* family produces large numbers of seeds and, in a normal situation, most of the seeds are lost: most are washed away downstream, becoming too waterlogged to germinate. Some settle too deeply into the mud and cannot germinate due to lack of oxygen; and some sink too deeply into the water and do not receive the amount of sunlight required to stimulate germination [99][100].

Papyrus Responses to Changing Physical Factors

In times of low water, the incidence of Papyrus pollen deposition rates in the Mediterranean decreased [101], implying that more remains within the river, increasing the potential for germination. In a low flood, conditions become less severe as the momentum of the water reduces: the water is not as deep, the flow less powerful and the mud becomes less fluid. A low Nile produces less turbulence which leads to lower rates of disturbance in the water; this lowers turbidity and allows light to penetrate deeper into the water encouraging plant growth [91]. More seeds would then survive, and, in these areas, seedlings have an increased chance of surviving to germination [90][100].

The power of the water affects the rate of erosion, thus impacting upon the width of the marshes [64]. A low Nile has less energy to carve out new channels so this increases the number of secondary channels [66]. The stability of the soil strata in which the Papyrus is growing is affected by the energy of the water that is flowing across it [63]. A weaker than usual river results in less volume of flowing

water, suggesting a commensurate decrease in the rate of erosion should occur. A low Nile also does not have the momentum to break up the Papyrus clumps [90][102]; over time, these islands increase in volume as they collect detritus [103]. As a consequence of this, the forces hindering the growth of Papyrus clumps would diminish, and so the size of Papyrus clumps would be expected to increase.

Once established, Papyrus send out rhizomes to spread along the nearby strata [103], but the spread of these rhizomes is usually limited by the power of the water [74]. The stability of stratum in which the Papyrus is growing is affected by the energy of the water that is flowing across it [63][83]. Both these circumstances should encourage rhizomes to spread more readily [100]. Papyrus displays the ability to grow on the edge of a riverbank as well as the capability to ‘clump’ upon itself, forming islands, which can affect the rate of flow of the river [104]. As a consequence of a low Nile, the forces hindering the ability of Papyrus to clump would diminish, and so the size of Papyrus clumps would be expected to increase [66][102]. Papyrus displays the capacity to exploit two distinct habitat types: waterway edges and shallow water [90]. This enhanced facility of Papyrus allows it to respond more readily from this situation when compared to similar plants [104] and can rapidly increase its own biomass and density [104]. In Egypt, this increased distribution of Papyrus plants did produce an effective obstacle; in Arabic, the term ‘sudd’ relates to such an obstacle or blockage within the river [74][102].

Papyrus Response to Changing Chemical Factors

The increasing number of secondary channels results in more areas where water flows with less energy than in the central part of the system [67][91]. With the water column becoming increasingly shallow, these areas have different evaporation rates, exhibiting chemical properties slightly different to other parts of the river [76]. Due to increased evaporation in shallow water, it is expected that the salinity levels within secondary channels would be higher than those in the main part of the river. It has been suggested that a low Nile may develop areas unfavorable to ‘normal’ life due to increasing salinity [66]. Papyrus appears able to tolerate slight increases in salinity [105]. In a ‘low flood’ those nutrients that were usually deposited upon the land in a ‘natural’ flood remain within a waterway, resulting in acidity levels different to what they would normally be [57]. Papyrus displays an ability to tolerate a wider range of acidity levels than similar plants [86], suggesting that Papyrus is well-suited to survive the chemical changes that could develop during times of low flow.

Papyrus Response to Changing Biological Factors

The inundation normally resulted in the deposition of

nutrients to the land adjacent to the river; this loss of nutrients inhibits Papyrus growth [106]. A lower than normal flood results in the nutrients are remaining within the band of Papyrus and other plants bordering the river. A low Nile allows for an increase in the growth rate of those organisms that “fix” nitrogen, improving the nutrient quality of the host, in this case the Papyrus [66]. Papyrus swamps present considerable absorbing surfaces as they spread out over the water at river and lake edges, and as the floating mats form, large amounts of nutrients are incorporated into the plant [66][100][107]. A reduction in water current leads to a larger area of sheltered living conditions at the river’s edges, which presents a contrast to the living conditions in the center of the river [68]. A low Nile, therefore, provides the impetus for a bloom of Papyrus.

Ecological Implications for Papyrus in Drought

While excess flooding and rapid drying events hinder germination [100], slight changes do not affect the setting of seeds. Salinity did not seem to impact upon the germination and growth of Papyrus. Papyrus is not affected by slight increases in temperature. It seems, that in response to a low Nile, one with a greater concentration of nutrients, with warmer than usual temperatures, less than regular flow and a slightly more saline environment, Papyrus would experience a significant boost to its survival chances in this new setting.

5. Phragmites and a River in Drought

Phragmites australis is another indigenous species historically that has long associations with historical Egypt. Known simple as a reed, Phragmites have been found growing in many diverse habitats, including freshwater marshes, oxbow lakes, swales, and backwater areas of river and streams, as well as on flat ground [108][71]. As with Papyrus, Phragmites can reproduce sexually and asexually; with Phragmites producing huge numbers of seeds that can be dispersed by wind as well as water. The main form of asexual propagation is the rhizome, but roots are also able to develop by ‘stolons:’ fragments of the rhizome that have settled above ground, on moist land [109]. Another form of asexual reproduction employed by Phragmites is the ability for any part of the stem that touches the ground to develop a root system [110].

Phragmites Responses to Changing Physical Factors

Phragmites are termed an “invasive” plant, since the Phragmites reed beds grow into the surrounding environment [111] [112] [113], spreading rapidly, weakening the soil by allowing water to trail along [112], thereby gaining ground [99]. Since flooding has been suggested as a control strategy [71] [114] [115], the

inference is that a weaker, lower river is conducive to Phragmites growth. Long term low water availability encourages Phragmites growth response in experimental ecology trials [116]. Along the Nile, with its many secondary channels, it would be expected that the reed populations would become more common in slow flowing water, especially in a season of low inundation. Phragmites’ internal structure allows it to resist dehydration, allowing it to survive extensive dry periods [74].

Phragmites Responses to Changing Chemical Factors

The reed seems to grow best in areas with stagnant water, displaying an ability to tolerate brackish conditions, when compared to other plants [118]. In the modern era, it has been shown that *Phragmites australis* growth has been promoted by an increase in soil salinity bought about as a consequence of de-icing roads and pathways, suggesting that Phragmites respond more favorably to an increase in salinity, than similar plants [115][119]. In some modern-day areas, some reed swamps tolerate such high levels of salinity that they appear as mono-cultures of this species [71]. This suggests an increase in water salt content due to higher rates of evaporation would have no detrimental effect upon its growth [117], inferring that Phragmites would be at an ecological advantage in situation of low flood.

Phragmites Responses to Changing Biological Factors

It appears the reed responds to an increase in nutrient supply in a similar manner to that described for Papyrus [112][113]. The reed seems to grow best in areas with slow water and silted substrates [71][116][120][121]. Its growth does not seem to be as impaired when its habitat turns eutrophic [116]. Because of the varied reproductive strategies available to Phragmites, the reed responds more rapidly to habitat disturbance [122][123].

Ecological Implications for Phragmites in Drought

In the more recent timeframe, various examples of human manipulation, impacts or disturbance of environments have promoted Phragmites [112] [115] [123] [124], and allow us to infer how the Phragmites would have responded to historical changes to its environment. These suggest that a weaker-than-normal flood event would not have hindered, but more likely encouraged Phragmites response.

6. Cattails and a River in Drought

The primary cattail, sometimes termed ‘bulrushes’, species *Typha domingensis*, is usually identified as being found in close proximity to another significant reed, Phragmites [71][125]. It is a tall marsh herb able to achieve

heights of up to 2–2.5m [126]. They propagate by seeds, which can be broadcast by wind [71], as well as by stout creeping rhizomes [126], but cannot spread beyond shallow water [71]. The growing reed are thought to be good cattle food [71][125].

Cattails Responses to Changing Physical Factors

Decreased erosion would have increased plant stability, but less powerful water flow results in a less disturbed sediment, slowing down *Typha* penetration [127] [128] [129]. *Typha* don't spread into water as shallow as that occupied by *Phragmites* [71]. Creeping rhizomes are so called because of the slow rate of movement, and the absence of new water limits the growth season [130]. Experimental investigation of the relationship between water flow and plants growth suggest that low water availability impairs the overall fitness of the species, but excess water also limits growth rate of the plant [131].

While higher than normal temperatures inhibit plant growth rates for *Typha* species [132], it has been shown that increased soil temperature slows the formation of new rhizomes but encourages rhizomes already present to grow more rapidly [126][133].

Cattails Responses to Changing Chemical Factors

Strongly acidic environments are toxic for the growth of *Typha* species [134]. *Typha* do not respond well in conditions more saline than natural [127]; as the salinity increases, their overall numbers decline [71][135], as well as limiting the spread of the rhizome [130][136]. However, *Typha* exhibit different sensitivities to salinity at different stages in their life cycle, displaying resilience to changing environmental situations [137]. While the mature plant can tolerate some minor salinity increase, seed germination and seedling growth is less resistant [137][138]. Root structure is modified when subjected to salt stress [134]. *Typha* are usually less dominant in the more saline parts of the swamps than are the *Phragmites* [71].

Cattails Responses to Changing Biological Factors

In waterways of highly nutritious sediment, cattails can predominate [71][139], with their deep roots allowing them to resist changes in soil quality, allowing the plant to be less affected by drying out of its territory [140]. An increase in phosphorus nutrition enables cattails to resist some of the negative effects of salt on their development [141]. An increase in nitrogen nutrients does not aid *Typha* growth but *Typha* appears able to resist the toxic effects of cyanobacteria [134][141]. As the soil becomes increasingly anaerobic, the lack of oxygen limits growth potential for the plant, comparing unfavorably with *Phragmites*' ability in this regard [71] [143].

Ecological Implications for Cattails in Drought

Typha plants can persist in condition detrimental to its survival by reverting to a dormant state until conditions improve [127]. *Typha* respond to changing environmental situation by adapting their reproductive strategies emphasizing the production of seeds or rhizomes [133][134]. This suggests that, while they may not grow in drought-like conditions, it can persist in an environment until the equilibrium is returned. The species appears capable of modifying its morphology in order to adapt to severe conditions; being resistant to cyanobacteria toxins suggests that it is more likely to persist in conditions where the waterway has become eutrophic [134]. In modern studies, *Phragmites australis* is identified as the most consequential reed in Egyptian swamp habitats [71]. *Phragmites* and *Typha* were recorded in close proximity to one another [142], seeming to contest similar habitats, with a community of *Typha domingensis* more likely to be overcome by *Phragmites* when they are in competition with one another [71]. So, overall a weaker flood would hinder *Typha* spread.

7. Lotus and a River in Drought

The plants identified as the blue and white Egyptian Lotus are members of the water lily family, *Nymphaea* [144][145], who prefer clear, warm, still, slightly acidic waters [147][148]. They reproduce using both seeds and rhizomes [71][149], and in optimum conditions Lotus spread rapidly due to its dual propagation strategies. The growth of lotus follows an annual cycle, removing the normal water supply can interfere with growth of the plant [150]. Plants take up to four years to grow from seed, implying that a rapid response to changing environmental factors would be difficult.

Lotus Responses to Changing Physical Factors

As the flow of a river decreases, erosion becomes less problematic with regards to the settling of a new Lotus into fine sediment [148][149][151][152]. They can survive briefly as a terrestrial plant, but cannot survive a long term significant fall in water level [71][147][149]. Because its leaves lie on the surface of the water [71], it's growth rate is not affected by changes in turbidity, however, it can shade other plants, lowering their ability for photosynthesis [148][149]. Changes in water temperature do not seem to hinder plant growth, but temperatures above 15°C accelerate the development of disease [147]. As the width of the secondary channels decreased, the rate of growth is slowed with *Typha* or *Phragmites* taking over [151].

Lotus Response to Changing Chemical and Biological Factors

Lotus growth responds poorly to strongly acidic soil

[147][149]. Although lotus grows best in acidic soil of pH 4.6, growth is not affected by water with pH values ranging from 5.5 to 8.0 [153], but increased salinity hinders growth [147][149].

While Lotus respond well to slight increases in nutrient levels in the water they struggle to grow when water conditions become more anaerobic [154]. Increasing nutrient concentration speeds up plant and rhizome growth [149][151] but hinders seedling germination [147][153]. Lower than normal oxygen content in the water also slows plant development [147], and if the oxygen content of the sediment declines, it limits the potential germination of the lotus seed [148].

Ecological Implications for Lotus in Drought

In a weaker flow more of the river would encompass areas where the water is shallower than normal, the flow is slower than natural; and the temperature is warmer than it would normally be. These imply a decrease in lotus abundance. Extra nutrients would initially encourage plant growth but then the anaerobic consequences of excess nutrients in the sediment slow rhizome growth and limit germination. A low Nile would be less beneficial to lotus growth.

8. Habitat Changes in Drought

The annual flood regularly experienced by the Nile maintained a reliable cleansing cycle to which the living things that came to rely upon it had become adapted [67]. If a system that is consistently flooded experiences drought, then the overall productivity of the primary producers would be less than normal due to a smaller-than-average water and nutrient supply [68]. Therefore, a series of long-term, non-flood events would impact upon those organisms that have adapted to a more drenched situation. In a 'regular' flood, the nutrients spilled over onto the nearby land, so were lost to the river. A slow river has less momentum within it, so it deposits alluvium more readily than a faster one [99][155]. Lower-than-average flood levels would have resulted in the formation of more secondary channels and therefore more areas where the flow was less than in the main body of the river.

Since it has been reported that swift water flows within a river results in a more rapid loss of carbon from that system [90], then it seems logical that the reverse is true. A low Nile has less momentum within it, so it deposits alluvium more readily than a faster one [57][99][155]. Thus, a low Nile would not clean out the detritus that had built up in the secondary channels as effectively, allowing for a rapid increase in biological material [67]. This affects the productivity of the primary producers (the plants), the variety of plant species, and the variety of food webs that the system can support [90]. The rate of cycling of nutrients

within the system is also affected by the amount of water flowing through it [90]. This change would affect the life cycles of the organisms within the river.

Whereas Papyrus clumps grow denser and taller [156], Phragmites species grow outwards and not up [71][107]. The large mass potential of Papyrus and Phragmites, and the extra height to which it can grow, produces a large number of 'micro-territories' available within their storeys, increasing the vertical habitat zonation of bird species [156], changing food webs associated with them [71]. As well as avian organisms, other terrestrial organisms, invertebrate and vertebrate, such as locusts and rodents utilize the centers of these masses as safe refuges [157]. Small carnivores are attracted to the increase in biomass in search of food or potential prey and have been described in, on and around the Papyrus [68][83][86][157]. As well as the increase in biomass build-up, decomposition will enable nutrients to be returned to the waterway to be in turn, re-absorbed by other components, especially microbes within the riverine food web [107].

Food Web Adaptations in Drought

Despite Papyrus and Phragmites being relatively insignificant plants within the food chains of larger herbivores, the highly productive vegetation has been identified as a valuable food source and habitat base for a wide variety of smaller fauna, both above and below the water surface [158]. A low Nile results in an increase in the amount of plant material under which fish species can exist [66]. Secondary channels provide an important role in the spawning activities of all fish species [67], whereas the deeper parts of the river provide for a greater variety of the bigger fish species [90]. Despite seeming "monotonous," in appearance [83], growing Papyrus clumps and Phragmites mats attract large shoals of fish [66][83] and higher numbers and varieties of animals and their predators, and this vegetative fringe has been identified as being the most biologically rich habitat of the river [68][156]. Migration of fish species can occur along the length of the river and within the different parts of the river, providing a variety of resources [83][86]. Considering the huge biomass potential along the fringes of the river [159], and the identification of small fish species as the most important faunal constituent of these vegetative fringes [68][83], then it is to be expected that a more determined effort to exploit this particular resource was undertaken.

When water flow in marshlands becomes more sluggish, these clogged parts of the river exhibit different oxygen characteristics than do the faster-flowing parts of the river. Fish distribution and abundance within the river may vary according to the particular stage in that organism's life cycle, or the amount of oxygen available for that particular species [160]. The varying speed of different parts of the river, with their inherently different oxygen availabilities can also become an effective barrier to the dispersal of

most species [160]. All these factors cause selection pressures on fish populations, leading to variances of distribution and abundance within local populations [160]. Catfish and lungfish appear less vulnerable to these changes [160]; this may mean they are better adapted to respond more rapidly to environmental change. A more detailed investigation of the fish species depicted within Egyptian tomb decoration scenes may identify whether these organisms change in abundance over the time frame under investigation.

As well as being an aquatic food source, Papyrus and Phragmites bloom expansion become a significant attractant to birdlife [90], with a direct relationship between an increase in marsh size and a corresponding increase in bird abundance being identified [157][161]. Modern investigations have recorded the rapid increase in numbers of ducks and geese in developing secondary channels; these channels having become important and secure nesting sites; among the modern-day avian visitors to the Nile, individuals of historically recorded species have also been identified [67]

Notwithstanding the high nutritive value of Papyrus and Phragmites, most large herbivores are poorly adapted to grazing upon sedge-type marshland flora such as Papyrus [162]. Moreover, the level of grazing has to be quite significant before it has a harmful impact upon the success of sedge type plants such as the Papyrus; these species can accept up to 40 per cent grazing and still experience viable reproductive success [163]. Cattle tend to eat the youngest and freshest shoots, but this damage by grazing animals seems to encourage regrowth and does not interfere significantly with the biomass output [156]. Most of the developing flower heads (the umbels) do not produce flowers but have an important photosynthetic value to the potential of the plant [159]. Since it is the older parts of the plant and rhizome that store the starch needed for the plant's metabolism, grazing upon the growing parts of a plant does not significantly impact upon its reproductive ability [162][164].

9. The River in Drought: A New Interpretation?

In times of a low flood, when the river did not overflow its banks, the nature of the physical, chemical and biological factors within the river would be different to those existing in normal situations [165]. Rzóška points out that, in terms of Papyrus marshes, a 'non-flood' event, or lack of inundation, is not a waste of water; it is merely a loss of water (and its accompanying nutrients) to those relying on the excess for success in agriculture [68].

Therefore, the environmental conditions would have become altered from the status quo. It seems that Papyrus and Phragmites appear to be well adapted to respond to the environmental changes that are proposed to have occurred

during a drought, compared to Typha and Lotus. These changes more than likely should have resulted in conditions that promoted growth of the Papyrus marshes and Phragmites reed beds.

The processes leading to the rapid growth of a Papyrus marshes and Phragmites mats could be summarized as follows. In the normal flood situation, as the river overflowed its banks, the nutrients carried within are deposited on the riverbanks along its length (see Figure 1: A regular inundation deposits resources onto the land).

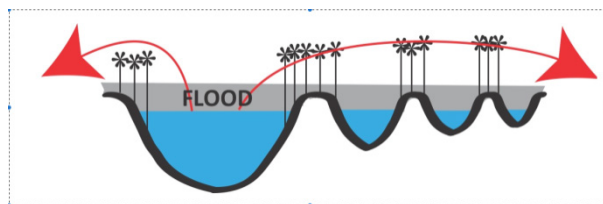


Figure 1. A regular inundation deposits resources onto the land

During time of 'drought', the river would still have carried these nutrients from downstream, but the river did not have the necessary volume to overflow its banks; resulting in the nutrients that it carried being retained within the river. As the current slowed, the potential energy of the water would have decreased, meaning that it would have lost the necessary momentum that was needed to carry these nutrients. Therefore, these nutrients would have been deposited on the riverbed and river's edges rather than beyond (see Figure 2: No inundation means that the nutrients remain in the river).

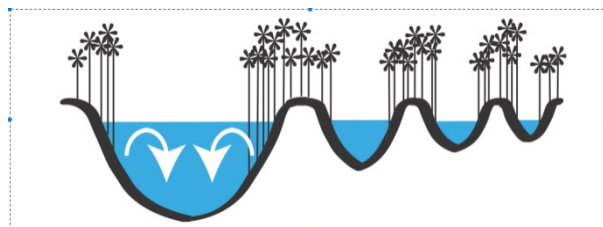


Figure 2. No inundation means that the nutrients remain in the river

The Effect of Drought upon the River

As a consequence of a long-term drought, the river became slower and lower and the circumstances outlined above would have been magnified. This build-up over time would be expected to have resulted in the nutrient level in the river increasing, providing the biological energy for a 'Papyrus bloom' and a Phragmites expansion.

From another perspective we should expect the river to have narrowed as the river volume (and therefore flow rate) decreased, allowing the Papyrus marshes and Phragmites reed beds to grow inwards towards the center of the river, (see Figure 3: Normal versus low Nile flow).

Ankhtify, the great overlord of the nomes of Edfu and Hierakonpolis, described the desperate situation that developed in the south of the country during the famine

[17][13][166]], and he also bemoaned the “*the House of Khui; inundated like a marsh (and) neglected by its keeper*” [166][167]. The ‘Marshes of Edfu,’ those that interfered with the grain distribution plans of Ankhtify [167][168], may have developed as the consequence of Papyrus and Phragmites bloom due to the retention of nutrients within the river.

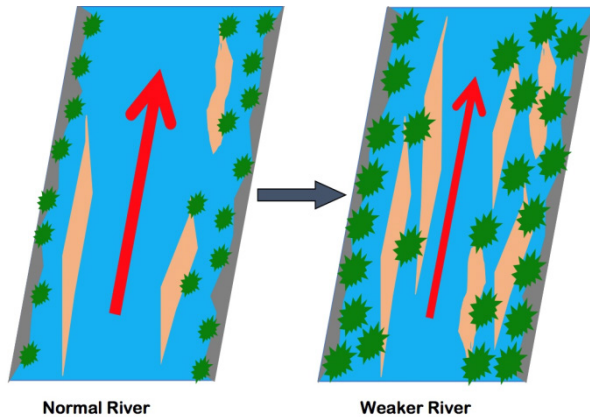


Figure 3. Normal versus weaker river flow

The increased development of *khors* and *sudds* along its length were a consequence of a lower, slower, weaker but more resource-rich waterway. The rapid growth of Papyrus clumps within the river and the spread of Phragmites mats from the riverbank effectively made the river smaller, hampering the movement up and downstream.

10. Conclusion: The Nile Blooms in Drought?

As the power of a river declines, the river is less able to carve its way through the environment so some of it branches into smaller and less powerful secondary channels. A weakening river is less energetic; the natural cleansing of the river that happened every season could not occur. A low Nile carries less sediment, so the deposition of nutrients occurs at different sites than normal. With less alluvial activity, the sediments and associated nutrients carried remained within the river. A low Nile allowed light to penetrate deeper increasing the depth of the photosynthetic zone. A low Nile produces larger temperature variances, the surface warms more readily and evaporation increases. A low Nile mixes its layer less, leading to more exaggerated differences in the properties of the separate water layers. A warmer river stores less oxygen than normal, limiting the oxygen availability for its constituent organisms, helping exacerbate the process of eutrophication. A low Nile results in less oxygen absorbance from the atmosphere. Increased evaporation changes the chemical composition of the waterway by increasing its salinity and changes in the aerobic capacity of the river changed its acidity.

Applying basic ecological principles, and using modern parallels, it seems reasonable to suggest that, due to an increased nutrient load, the ecological properties of the river would have changed. The number and variety of food chains present would have changed dramatically, resulting in circumstances which some plant species would find more beneficial than others. In completing a brief overview of only four Nilotic plant species, and the suspected changes they would experience due to a weakened river, the ecological principles applied imply that the habitat would change. A ‘drought’ would have resulted in a river with a smaller free flowing main channel with shallower and warmer secondary channels becoming increasingly clogged with thick Papyrus clumps and Phragmites mats spreading towards the middle, with other significant plant groups such as the cattails and lotus lessening in numbers. Therefore, the ecological interactions would not be the same as those experienced in “normal” times.

In trying to understand the consequences of a weakened river at the end of the Egyptian Old Kingdom, the application of simple environmental approaches may be of value in suggesting how the habitats changed and may also allow inferences to be made with regard to how the society adapted. Future investigations may be undertaken in order to test the veracity of the entire hypothesis.

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