

CLIMATE CHANGE AND CRISIS IN OTTOMAN TURKEY AND THE BALKANS, 1590-1710

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INTRODUCTION

In the past decade, interest in global warming has prompted the creation of ever more complete, extensive, and accurate climate reconstructions for the eastern Mediterranean region. In addition to their contributions to climatology, these studies provide invaluable insights to historians. Chief among these is the close timing of severe weather events and crisis in the 17th century Ottoman Empire, which then ruled from Hungary to the Hijaz. This paper will examine the possible links between climate and crisis in Anatolia and the southern Balkans, focusing on two key periods of “Little Ice Age” weather, 1590-1620 and 1680-1700.

The Seventeenth-Century Crisis

In the seventeenth century, the Ottoman Empire (c.1300-1923) suffered a major crisis from which it never fully recovered. After reaching its zenith in the mid-1500s, the empire began to suffer from increasing economic turmoil and social unrest (Akdağ 1963 and 1971). Beginning in the 1590s, a series of rebellions known as “Celâlîs” swept the countryside, driving peasants into flight and leaving large parts of the Greek and Turkish depopulated (Griswold 1983; Hutteroth 1968). The crisis persisted through the 1600s, and despite the resilience of the Ottoman state, its attempts to restore order and resettle the land met with little success (Barkey 1994; Darling 1996; Orhonlu 1963). By the end of the century, the empire had lost much control over the provinces and began to face defeat on the battlefield at the hands of the rising Russian and Hapsburg empires.

Underlying this entire crisis was a sudden demographic shift. While there are no complete censuses of Ottoman lands before the 19th century, regional studies based on a variety of tax records reveal a consistent and striking pattern. Many regions of Anatolia and present-day Greece, after a century of rapid growth, were suddenly emptied of half or more of their people. Table 1 gives a small but representative sample of the depopulation that occurred. Many of the the people seem to have fled to secure locations in the hills or in cities, but a great deal had simply vanished (Özel 2004). By the mid-1800s, the region’s population was still down, and its share of world population had fallen to perhaps a quarter of its peak around 1590 (Arslan 2001; Karpat 1985; Livvi-Bacci 2001).

Table 1. Population change in several sancaks and kazas in Anatolia and Greece (Erder and Faroqhi 1979; Kiel 1997 and 1999; Özel 2004; Öz 2004) Tables are given in households (*hane*) or adult male taxpayers (*nefer*). Note that there is an extensive literature on the meaning of these terms and figures, and I have only used studies that were careful to control for the effects of changes in Ottoman terminology and bureaucratic methods.

Region	1520s-50s	1560s-90s	1610s-40s	Region	1520s-50s	1560s-90s	1610s-40s
Karahisar	6,661	13,679	7,755	Atalanti	1,353	1,810	960
Kocaeli	5,439	-	4,730	Boeotia (4 villages)	238	256	211
Bafra	-	3,546	1,415	Bozok	-	41,484	4,461
Samsun	-	39,609	6,068	Amasya		12,923	833

The traditional historiography used to blame this decline on degenerate sultans and viziers who strayed from Ottoman political and military traditions. In the 1950s, historians of the French Annales school were the first to link these events with environmental factors, including climate (Braudel 1949; Utterstrom 1955; Barkan 1980; Aymard 1966; İnalçık 1978). Peter Kuniholm, who compiled the first tree-ring databases for the Aegean region, also observed the striking correlation between poor growing seasons and disasters in the Ottoman Near East (Kuniholm 1990). Unfortunately, the necessary evidence was lacking and the links between the Little Ice Age in northern Europe and weather in the eastern Mediterranean were not well understood (Le Roy Ladurie 1971; Lamb 1995). Several scholars have raised the issue since, but without more conclusive evidence (Gerber 1989; Griswold 1993; Darling 1996). Most historians continue to downplay the role of climate and to focus on such explanations as the “price revolution”, transition from feudal cavalry to gunpowder infantry armies or the rising competition from European merchants.

The Little Ice Age and Climate in the Ottoman Near East

In the past decade, however, our understanding of the Little Ice Age (LIA) in general, and eastern Mediterranean climate in particular, has come a very long way and demands we reconsider the role of climate in Ottoman history. The new findings relevant to the present study may be briefly summarized as follows:

(1) High-resolution proxy reconstructions and careful study of historical documents have deeply enhanced our knowledge of LIA climate events (for the state of the field see Bradzil et al. 2005). Once defined broadly by eras of glacial advance, the LIA can now be defined in terms of particular weather events clustered in certain multi-decadal periods from c.1300 to 1870 (Grove 1988; Pfister et al. 1999; Fagan 2000; Pfister 2005). Among the most severe such periods were those from the 1570s to 1610s and the 1670s to 1710s, the latter sometimes referred to as the “Late Maunder Minimum” (Pfister 1994 and 2005; Luterbacher et al. 2001; Xoplaki et al. 2001).

(2) Two major theories have surfaced to explain these swings in European climate. The first explanation is that volcanic activity created dust veils, reducing solar input and causing cold, abnormal weather. There is strong evidence in Northern Hemisphere (NH) ice cores for such volcanic activity in these phases of the LIA, particularly around 1600, and further evidence that volcanic dust reduced temperatures (Lamb 1970; Briffa et al 1998; De Silva and Zielinski 1998; Free and Robock 1999; Luterbacher et al. 2001; Schindell et al. 2004). The second

explanation, not exclusive of the first, focuses on the impact of the North Atlantic Oscillation (NAO). Recent detailed reconstructions of the NAO index (measured by the difference in sea surface pressure (SSP) between the Azores High (AH) and Iceland Low (IL)) reveal significant swings in the period under consideration (Luterbacher et al. 2002). NAOI activity has been closely correlated with a variety of weather events over Europe and may explain most of the unusual cooling and precipitation characteristic of the period (Fagan 2000; Luterbacher and Xoplaki 2002).

(3) Both these theories carry significant implications for LIA weather in the eastern Mediterranean. In the case of volcanic activity, dust veil events have been observed to produce severe weather (usually cooling) and volcanic “dry fogs” linked to crop failures and epidemics (Camuffo and Enzi 1994; Stothers 1999, Schindell et al. 2004). In the case of NAOI fluctuations, a number of publications in the past six years have given increasing weight to NAO influence on precipitation in the Near East and particularly the Aegean region (Cullen and DeMenocal 2000; Felis et al. 2000; Grove 2001; Cullen et al. 2002; Mann 2002; Xoplaki et al. 2004). While this influence fades eastwards across the Mediterranean and Middle East (Enzel et al. 2003), stations in Turkey still record composite winter (DJFM) dry conditions significant at as much as 69% for strong phases of the NAOI (measured by Ponta Delgada-Reykjavik SSP differences) (Türkeş and Erlat 2005).

(4) Recent climate reconstructions of the eastern Mediterranean offer a far more detailed picture of Ottoman climate anomalies and one that supports a connection with the European LIA (for an overview see Luterbacher et al. in press). First, both Kunniholm’s and other regional tree-ring sequences have been closely correlated with spring-summer precipitation, permitting the first true dendroclimatology studies of Ottoman lands. These studies confirm both that the empire suffered from significant periods of drought—including the longest dry spell in 600 years, 1591-1595—and that these droughts are significantly correlated with reconstructed NAOIs (Akkemik et al. 2005; Akkemik and Aras 2005; D’Arrigo and Cullen 2001; Touchan et al. 1999, 2002, 2005, and 2005b). Second, data from multivariate regional climate reconstructions and especially historical records from Ottoman, Greek, and Venetian sources demonstrate that the region also suffered from the unusually severe winters characteristic of European LIA climate events (Aymard 1966; Griswold 1993; Grove and Conterio 1994 and 1995; Güçer 1964; Kılıç 2001; Kunniholm 1990; Luterbacher and Xoplaki 2002; Racz 1997 and 1994; Repapis et al. 1989; Xoplaki et al. 2001).

Drawing these studies together, we can paint the following picture of climate in the 17th century Ottoman Empire. Though the weather was not uniformly cold and dry, it was marked by more frequent and extreme cold events than at present, and several significant periods of drought. Furthermore, these events appear more concentrated in winter and spring than summer or fall – certainly not the frequent cold, wet summers that mark the northern European LIA. Furthermore, LIA-type climate events were clustered in the two multi-decadal periods mentioned above, seemingly tied to a coincidence of NAO activity and volcanic events. The data is still far from complete, but when displayed together it presents a striking picture, and one which fits with observations of LIA weather in Mediterranean Europe (Grove and Rackham 2001).

Figure 2 demonstrates both the unusual clustering of extreme weather events and their close association with famines and other disasters of the 17th century in the eastern Mediterranean. Names and dates on the left display the standard deviations from recent mean precipitation evidenced by the respective dendroclimatology studies for the eastern Mediterranean as a whole (Touchan), the western Black Sea region (Akkemik), western Anatolia (D'Arrigo), south central Turkey (Aras), and southern Jordan (Touchan). Information for Crete and Greece are based on studies of Venetian archives and monastery records, respectively (Grove and Conterio 1994 and 1995; Repapis et al. 1989; Xoplaki et al. 2004). Of particular interest is the period 1590-1620, marked by both the most extreme climate events and the most devastating setbacks for the Ottoman Empire. In looking at the long-term impact of climate, moreover, the severe weather of the 1680s and 1690s may have been just as important, upsetting a potential Ottoman recovery and coming at a time the empire's first major military defeat in almost 300 years. Viewed this way, the timing of LIA events with historical events makes a strong though circumstantial case for climate-related disaster.

Figure 2A: Illustrating Climate Events in the Ottoman Empire 1570-1625

Year	Touchan	Crete	Greece	Other Weather Events	Other Events	Touchan
1570		drought			locust invasions in Italy this decade	
1571					rising grain prices; prohibitions on export	
1572					severe winters in Anatolia; epidemic in	
1573					Salonica then Cyprus and Edirne	
1574					famine in Anatolia	
1575		severe winter			famine continues	
1576		severe winter			famine, widespread epidemic in Anatolia	
1577			severe winter; frozen lakes and rivers			
1578					locust invasion in Azak	
1579					famine across E Med; epidemic in Salonica	
1580					shortage in western Anatolia	
1581						
1582						
1583					drought in Syria	
1584					drought and famine in Syria, Anatolia and	
1585		severe winter			Aegean (1584-5); coinage debased	
1586		severe winter			locusts and famine in Çorum	
1587				dry fog in Italy		
1588		very severe winter			shortage in Istanbul	
1589		drought and famine			shortage in Levant, Janissary revolt	
1590		very severe winter	severe winter		shortage in Damascus; epidemics in	
1591	longest	very severe winter			Istanbul (1590, 1592)	
1592	recorded			dry fog in Italy	famine in Damascus; beginning of	
1593	dry period				plague outbreak in Anatolia	
1594	in 600 yrs	very severe winter			prohibition on grain exports	
1595	1591-5	terrible drought and famine		Danube freezes	invasion of mice in Trablusgarp; famine	
1596					outbreak of Celali uprisings	
1597						
1598					famine; epidemic in Istanbul	
1599						
1600					locust invasions in Italy this decade	
1601	longest	very severe winter		eruption of Mt. Huaynaputina, dust veils	beginning of "great flight"	
1602	recorded	very severe winter		Danube freezes (1601/2)		
1603	wet period					
1604	in 600 yrs	very severe winter				

1605	1601-5						
1606						Canbuladoglu rebellion in Syria	
1607	extreme				Danube freezes; probably coldest		
1608	drought	very severe winter; snow	severe winter; freezing lakes and		European winter in last 1000 years		recurring
1609						shortage in Crimea, western Anatolia	drought
1610	drought					locust invasion in Turkey	`
1611						famine in Anatolia; recurring locusts	`
1612					snowy winter	invasions in Cyprus 1610-1628; epidemic	`
1613		drought				in Istanbul (1612); drought in Syria	`
1614						shortage in Damascus	`
1615						shortage in Zulkadrlu	`
1616							`
1617		severe winter; deluge					`
1618							`
1619							`
1620					Bosphorus freezes; dry fog in Italy		`
1621							`
1622			severe winter; freezing lakes and			Sultan Osman deposed	
1623							
1624							
1625		drought and flight				major epidemic in Istanbul	

Figure 2B: Illustrating Climate Events in the Ottoman Empire 1670-1725

Year	Akkemik	D'Arrigo	Aras	Touchan	Greece	Other Weather Events	Other Events
1670							
1671							
1672						drought and dry fog in Aegean	
1673							
1674	1						
1675	1					(approximate beginning of LMM)	
1676	-1				extremely cold winter		
1677							
1678	1						epidemic in Manisa
1679	-1				cold wet winter		
1680							
1681							

1682					severe winter and famine	dry fog in Italy	
1683					severe winter, heavy snows		
1684						extremely severe winter in Italy	
1685							
1686					cold, wet winter	harsh winter, ice on Golden Horn	
1687	-2	-1			severe winter; frozen lakes and rivers		Ottoman defeat at Mohacs; famine in Balkans
1688		-1	_____	recurring			
1689	2	2	1	drought		dry fog in Italy 1689, possibly 1690	flooding in Edirne area
1690				`	famine in Athens	volcanic eruptions, extreme cold and	
1691				`	drought and famine in Crete	famines in northern Europe and	major state nomad settlement policy effort
1692	-2		2	`		Spain this decade	in Syria
1693			-2	`	`		`
1694			-1	`	`		`
1695				`	drought spreads across Aegean	possible volcanic event	`
1696	-2	-2	-1	`	`		`
1697				`			
1698				`		possible volcanic event	
1699							Treaty of Karlowitz concludes first major
1700					severe winter		Ottoman defeat in three centuries
1701	-2						
1702							
1703							Mustafa II deposed
1704							
1705							
1706							
1707	-1						
1708	-1					cold famine and plague in Serbia	
1709	2	2	2			extremely severe winter in Italy and Hungary	
1710					drought in Ionian	dry fog in Italy	
1711					`	locust invasion in Ioannina	
1712					drought and famine		
1713					`		
1714			-1		`	severe winter drought across E Med	
1715	-1		-1		`		
1716							
1717			2				
1718							

1719							
1720	1						
1721			1				
1722							
1723	2						
1724	-1		1				
1725	-1	-1	-2				famine; outbreak of plague

Sources: Akkemik et al. 2005; Akkemik and Aras 2005; Aymard 1966; Briffa et al. 1998; Camuffo and Enzi 1991, 1994, and 1994b; D'Arrigo and Cullen 2001; Faroqhi 1999; Grove and Conterio 1994 and 1995; Güçer 1964; Kılıç 2001 and 2004;Kunniholm 1990; Luterbacher et al. 2004; Racz 1992 and 1994; Repapis et al. 1989; Touchan et al. 1999; Touchan et al. 2002, 2005, and 2005b; Xoplaki et al. 2001 and mühimme defters)

Connections between Climate and Crisis

Evidence from Ottoman records permits us to take the argument for climate-related disaster one step further. While Ottoman archives do not contain the bills of mortality or parish registers available to European researchers, they do contain a wealth of information on population, prices, and output, as well as anecdotal evidence of famines and epidemics. This information was not collected consistently nor on an annual timescale appropriate for statistical correlations, but it is extensive and can be highly indicative of broader trends, as with the population data displayed above. Building on models from better documented European studies of LIA mortality crises, this evidence strongly reinforces the case for climatic impacts in the 17th century crisis.

First, case studies of European famines demonstrate that the most important weather events in terms of mortality were those that produced harvest failures and drove up prices of basic foods. These effects were particularly devastating where poor harvests persisted for two or more years, where there was no second harvest season to offset the failure of the first, or where access to wider markets was limited (Appleby 1978; Walker and Schofield 1989; Dupâquier 1989). On this basis, LIA weather events in Ottoman Anatolia and the southern Balkans were precisely the sort for creating famines. As shown above, drought and severe winters often persisted for several years. At that time, the region relied overwhelmingly on a single crop of winter wheat and barley, whose yields demonstrate an overwhelming correlation with spring precipitation and significant correlation with temperature at germination as well (May 1961; Özkan and Akçaöz 2001). Furthermore, outside of major cities food markets were highly localized, providing few alternatives in the event of a regional harvest failure (Faroqhi 1985; Güçer 1951 and 1964; İslamoğlu-İnan 1984). In Grove and Conterio's study of Crete (1547-1645), for instance, famine followed drought in 10 years, with only three instances where two successive seasons of drought did not create famine and no cases of famine without drought proceeding in either winter or spring (Grove and Conterio 1995).

Second, European examples confirm that famines were most likely to occur where pressure on the land was highest and landholdings small or marginal (Appleby 1978). In the Ottoman case, the first phase of these LIA impacts came at a time of rapidly rising population and declining per capita food output (Cook 1972; İslamoğlu-İnan 1994; Oktay 2004; Venke 1984). By 1590, harvests were barely above the subsistence level in some regions, landholdings had fragmented, and peasants were putting pastures and woodlands under the plow. Reconstructed price indices for Ottoman lands show a definite rise in the cost of foodstuffs in the later 16th century, a sharp spike in the crisis years 1590-1620, and another rise over the second period of LIA weather events in the late 1600s (Barkan 1974; Pamuk 2000). Some local price indices also reveal a particular increase in the years of prolonged drought shown for the 1590s (Faroqhi 1985).

Third, the breakdown of deaths by season and age indicate that diseases frequently killed more people than starvation in European LIA mortality crises. Disease could strike in one or more of three ways: (a) opportunistic infections bred by starvation, (b) infections bred by poor sanitary and living conditions among famine refugees, and (c) diseases bred by the crowding of famine refugees in population centers (Walker and Schofield 1989; Livvi-Bacci 1991). While (c) diseases may seem the most removed threat, they were frequently the leading cause

of mortality, usually in cases of typhus (Galloway 1985 and 1988). Case studies further illustrate that the most important variable determining mortality from type (b) and (c) diseases was the maintenance of public order in the countryside to prevent refugee conditions and population movements (Post 1985).

Once again, Ottoman evidence strongly confirms the application of European models and emphasizes the role of LIA mortality in the 17th century crisis. Ottoman records of the 16th and 17th century indicate that famines frequently drove peasants into flight or brigandage, and public order in the countryside was often in shambles, not least during the above-mentioned Celâlî uprisings (Akdağ 1963; Arslan 2001; Gümüüşcü 2004). More specifically, we have indications that rural populations fled to urban centers, sometimes hundreds of miles away. (Behar 1996; Gerber 1988; Oktay 2004). While we have little direct evidence that these refugees brought epidemics, the timing of three outbreaks in Istanbul in the 1590s is suggestive (see Figure 2). Furthermore, in the rare instances where demographers can reconstruct seasonal mortality in cities during crisis years, there are clear peaks in summer and winter months characteristic of epidemic outbreaks, or in autumn months, characteristic of famine (Establet and Pascual 1994; Özdeğer 1988).

Two additional factors, particular to the Ottoman case, may help explain the higher mortality of the 17th century. First, the abandonment of so much land, along with the changes in climate, may have created breeding grounds for mosquitoes and other insects, and thus malaria and locust invasions (Jennings 1988; Camuffo and Enzi 1991; Tabak 2000). These connections are, however, highly tentative. While it is clear that Anatolia and the southern Balkans saw some land clearance, erosion, and alluviation in Ottoman times, the causes are uncertain and not closely tied with these LIA events (Vita-Finzi 1969; van Andel et al. 1990; Bintliff 2002). Moreover, the connections between environmental changes and locust swarms are only hypothetical; and the evidence for widespread malaria is ambiguous, at least until the late 19th century (Lewis 1949; Bruce-Chwatt and Zulueta 1980; Frangakis and Wagstaff 1987 and 1992).

Second, the Ottoman Empire did not develop effective quarantine measures against bubonic plague in the 17th century, a time when Europe finally managed to contain that epidemic. While this failure has traditionally been attributed to Muslim fatalism, there are sufficient examples to show that Ottoman Turks did indeed take measures against the disease (Jennings 1999; Kılıç 2004). At the very least, there are numerous examples in Ottoman *mühimme defters* (petitions to the sultan) indicating that the state tried to keep peasants from fleeing plague-ridden lands, which would have helped contain the infection. The disorder and population movements of the 17th century crisis would presumably have undermined even these simple measures and precluded anything so ambitious as quarantine. Nevertheless, chronologies of plague in the Ottoman Empire show no special frequency of outbreaks in the 1600s, nor any one exceptional pandemic (Biraben 1975; Dols 1979). In fact, the weight of the evidence suggests that plague was worse in the 18th century, when overall population may actually have risen (Panzac 1985).

In examining the long-term impact of climate-related crises, the crucial factor appears instead to be a fundamental shift in the balance of people and resources. The 1500s witnessed a virtuous circle of population growth, agricultural intensification, rising population, and public

security—the fruits of a deliberate state policy of rural settlement. When crisis struck, this policy unravelled creating a downward spiral of population loss, disorder, and abandonment of cultivation. State policies on the one hand and the ecology of land use on the other must have aggravated this crisis. The state inadvertently encouraged migration to major cities, especially Istanbul, by diverting tax revenue and focusing its efforts at provisioning and security there. Even as overall population fell in the 1600s, urban population rose considerably (Behar 1996; Özel 2004). Early modern cities in general had much higher mortality rates than the countryside, and the endemic crowd diseases of a metropolis like Istanbul would have been particularly deadly for rural migrants lacking immunity (Landers 1987 and 1989; Lowry 2003). Combined with what appears to be a smaller family size in urban centers (Duben 1985), the shift in population to the cities would have represented a huge demographic drain over the 17th and 18th centuries.

Ottoman lands were also especially vulnerable to a resurgence of pastoral nomadism. This low intensity and mobile form of land use, long established in the region but closely controlled by the 16th century state, probably offered more flexibility and security in times of crisis. Once lands reverted to nomads, however, settled farmers were vulnerable to raids and the destruction of fields (Arslan 2001; Lidner 1983; Planhol 1958 and 1959). The Ottoman Empire made repeated attempts to settle nomads and expand cultivation in the 17th and 18th centuries, but without success (Orhonlu 1963; Faroqhi 1984). At least one such attempt, that of the 1680s-1690s, was probably derailed by persistent drought (see Figure 2). However, the effort as a whole appears to have fallen victim to a general downward spiral of population and security. The implication is that the 17th century crisis took on a momentum of its own, fueled at least in part by LIA climate events.

CONCLUSION

Based on the foregoing evidence, the likely patterns of short-term and long-term LIA climate-related mortality in the Ottoman Empire have been outlined in Figure 1. While these connections are tentative, there is good reason to believe that further detailed studies will support them. Of course, the prominent role played by the breakdown of public order indicates that such climate-based models can never operate independently of wider social and political frameworks. Population pressure, state policies, and other social and economic trends cited by Ottomanists certainly played a crucial role in the 17th century crisis. Notwithstanding, climate events offer a more compelling reason for the immediate outbreak of disorder and mortality in the 1590s than any of these conventional explanations. The timing simply fits better, and the scale and suddenness of the outbreak are better accounted for. Furthermore, the role of LIA climate events ties the Ottoman crisis to the general crisis of the 17th century observed from China to England and even the Americas. As recent historiography has put more emphasis on the role of climate and population loss in these disasters, the Ottoman Empire fits into the general trend (Goldstone 1991; Parker and Smith 1997; Pfister 2005; Souden 1985). Analysis of LIA influence on the Ottoman crisis also sheds light on the supposed role of climate in the collapse of ancient Near Eastern civilizations, for which few records survive (Issar and Zohar 2004; Neumann and Parpola 1987; Weiss 1982).

A complete account of this crisis, however, awaits a full consideration of the evidence and a wider study of climatic factors. The Ottoman archives contain far more information on weather events than what is already gathered here, and reports by European officials and travellers promise far more still. Nor have climatologists yet analyzed all the major factors involved in the region's climate history: NAOI and Mediterranean influences are far better understood than those of the Siberian High or weather across Central Asia and Iran. Moreover, dendroclimatology has revealed much about precipitation, but little about temperature. In this regard, historians and climatologists must continue working together to fill in the gaps in our understanding of Middle East climate change and its historical impact.

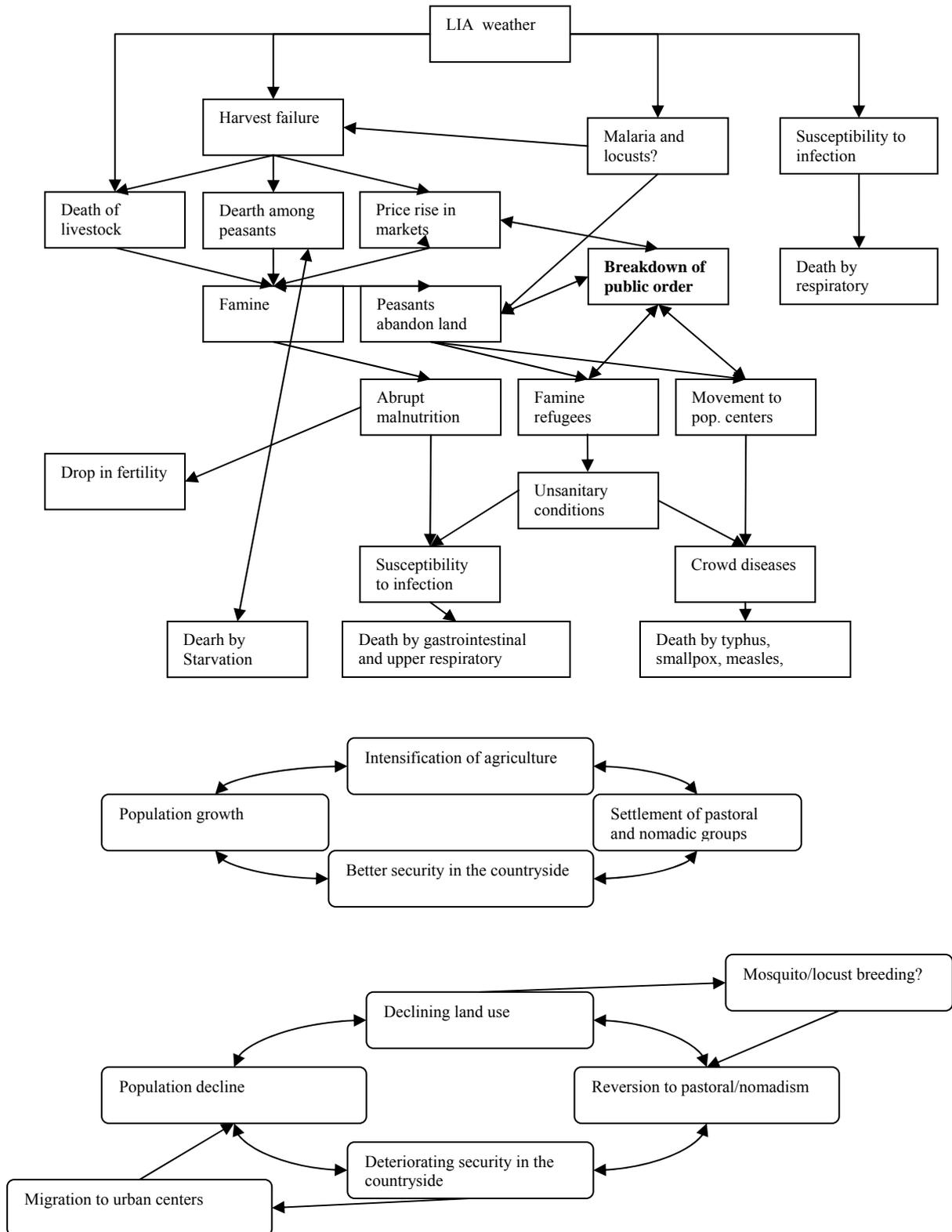


Figure 1. Illustrating the probable links between LIA events and mortality in the Ottoman Empire, the positive population feedback loop of the 16th century and the negative population feedback loop of the 17th century crisis.

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EXPANSION AND RETRACTION: PRECIPITATION-INDUCED CHANGES IN HUMAN SETTLEMENT

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ABSTRACT

The history of the ancient civilizations of the Near East shows numerous periods when settlement expanded into, or contracted from, semi-arid zones, as well as times when societies collapsed. Many of these episodes can be attributed to climate change. Five periods of climate change that impacted human settlement from the Younger Dryas to the mid-Holocene are described. These cases underscore the sensitivity of the Near East to changes in precipitation, both world-wide and episodic, and short-term and local. Past societies have risen and fallen repeatedly, in part as a consequence of climatic changes, but because of the extensive development of industrial agriculture, coupled with population increase, that have left no arable land undeveloped, there is less resilience in the systems today. More precise information on the extent and nature of climate changes, as well as further archaeological research will be necessary to fully comprehend the role of climate in history, as well as its potential role in the future.

INTRODUCTION

More than 5000 years ago, the Middle East was one of the birth places of agrarian civilizations and even today in the absence of substantial mineral resources the economies of the region remain heavily dependent on agriculture. With mechanization and vast irrigation projects agriculture has expanded well beyond the limits of natural precipitation and stream flow. Coupled with rapid population increase, the impact on the land has been transforming and it is hard to find any part of the landscape that has not been modified by humans. The rapid development during the last half of the 20th century is unprecedented and was built on relatively stable climate. We know from history, archaeology and a host of climate proxies, however, that climate has not always been stable; in fact it has been a determining factor in the fortunes of societies at least from the time of the Younger Dryas.

Throughout the history of the Middle East changes in climate, especially precipitation, have led to expansion or retraction of settlement. This effect has been especially pronounced in the semi-arid zones where precipitation strongly influences vegetation and the availability of surface water. The region today is dominated by strong seasonal contrasts, with nearly all precipitation falling in the cool months when evapotranspiration is low. Because the region is generally dry, interannual variability can be extreme (Amiran 1991:157). Agriculture depends on the gross amount of precipitation, its seasonal and interannual variability and winter temperature, which may impact cold-sensitive vegetation. These factors affect the length of dormancy and the month when annuals ripen. Timing of both the start and end of the growing season are critical, so that even small climate changes can have great impact. A shift of several weeks in the onset of the growing season, as is occurring today in some parts of the northern hemisphere, most likely would be problematic for agriculture in the Near East.

In this short paper I discuss how changes in precipitation affected humans during five crucial climatic periods: the Late Glacial-Younger Dryas, the Holocene Thermal Maximum, the 8.2 ky event, the moist 5.0-4.2 period, and the 4.2 ky event, all of which are well represented in proxy records. In all these cases, archaeology shows cycles of expansion and retraction of settlement, particularly in the arid zones, that can be attributed convincingly to changes in precipitation. While these cases occurred before the advent of history, they offer useful examples of what might happen today. Similar changes in precipitation, but of lower amplitude, have been felt up to modern times. Coupled with extraordinary human-induced changes in the landscape and population increase, even an historically minor decadal drought could have devastating effects (Hole 2004, 2006, 2007).

There are many studies of individual climate proxies and a few overviews of the climate since the LGM for the Near East (Issar 2004; Robinson 2006). While chemical and geological evidence is quite specific, there are few kinds of archaeological evidence that inform on climate directly so it is necessary to try to establish correspondences between known climate events and changes in archaeological remains. Because the number of archaeological data points (that is, surveyed, excavated and analyzed sites) is very small compared with time measured in millennia, and over space measured in hundreds of thousands of km, we often can only approximate temporal correspondence within a range of a few hundred years. In the historic era, while dating may become more precise, documents rarely describe the weather. In short, there are many uncertainties in determining just how a particular climate event impacted people. With this caveat in mind, I shall now discuss climate events that are widely accepted and can be recognized archaeologically through changes in the pattern of settlement. While all of the Middle East was affected by climate changes, some regions stand out because the necessary archaeological work has been done and the regions themselves are sensitive to climate change. The examples are the Levantine Corridor, centered on the rift that includes the Dead Sea and runs from the Gulf of Aqaba to southern Turkey, and the central Jazirah, the semi-arid plains that are framed by the Euphrates and Tigris rivers. The region shares the seasonal climate with the Levant, but has a striking north-south fall-off in precipitation. The zone close to the Turkish border has ample rain to support rain-fed agriculture, but within 50 km the drop in precipitation and rise of interannual variability render rain-fed agriculture problematic; and a short distance farther the land becomes suitable only for grazing. A similar gradient is seen in the Levant from west to east and north to south, but the Levant is much more complex topographically and has a greater range of precipitation.

THE BØLLING-ALLERØD- YOUNGER DRYAS

Following the Last Glacial Maximum, the Allerød warming trend (14.7-12.9 ky (Sima 2004) set the stage for one of the best recorded instances of the adverse effect of climate on people. The later stages of the Allerød saw the growth of stands of edible grasses and other plants in the Levantine Corridor, a uniquely diverse landscape that held niches in which species enjoyed enough protection to have survived glacial conditions (van Zeist 1982). As climate ameliorated following the LGM the vegetation began to emerge from the protected niches and expand sufficiently to be attractive as human food (Kislev 1992; Nadel 2001). It was during this period of relative prosperity that the Natufian culture expanded.

A large literature is available on the nature, duration and cause of the Younger Dryas (Alley 2000; Issar 2004; Taylor 1997:825-827; Robinson 2006:1536). The YD lasted approximately 1300 years (based on GISP2), from 12.9-11.6 ky (Sima 2004:741), “Much of the earth experienced abrupt climate change synchronous with Greenland within thirty years or less” (Alley 2000:213). However, “as soon as the Younger Dryas onset occurs, a climatic amelioration trend appears...until an optimum at 9.5-10 ka is reached” (Genty 2006). At Lake Van the Younger Dryas is characterized by near glacial cold and as much as 20-30 % lower precipitation” (Lemcke 2000:671). The best local record for the Younger Dryas is at Soreq Cave but cold and aridity are also indicated by low levels of Lake Lisan, dune formation, and pollen data (Margaritz 1987).

THE NATUFIAN

Culturally the Natufian period is a terminal stage of hunter-gatherers who, for the most part were mobile, depending for their subsistence on following ripening vegetation and herbivorous ungulates. Based on chronology and slight changes in the lithic technology the Natufian is divided into Early and Late phases. The Early Natufian (14,250-12,800 BP) developed out of the preceding Geometric Kebaran during the Allerød period. Some of the Early Natufians established permanent settlements in the Mediterranean zone where they had access to food resources the year round (Bar-Yosef 2001). At this time Lake Lisan was vastly larger than the Dead Sea today and there were numerous playa lakes in the eastern desert (McCorriston 1991: Fig. 2). Many of the Natufian groups exploited these playa locations seasonally and probably had only a semi-sedentary mode of living. The important point is that the semi-arid territory in which these sites occur has not seen permanent settlement again until recent times.

The rapid onset of the Younger Dryas caused a dramatic reversal of fortune for the Late Natufians (Bar-Yosef 2002). The far-flung sites in the arid steppe were abandoned and the remaining people clustered in the Mediterranean zone, but the sites were smaller, occupied only intermittently, and there was a loss of some of the more decorative elements that had characterized the earlier Natufians. The evidence implies a dramatic reduction of population and a reversion to a more mobile lifestyle.

During the Younger Dryas there are only sparse traces of human activity outside the Levant, probably because similar food resources did not exist (Hole 1989; 1996). While one can make this case for the Jazirah (the steppe between the Euphrates and Tigris rivers), it is possibly not true for the region of the Persian Gulf where aquatic resources and warmer temperatures may have fostered a different and flourishing hunter-gatherer life style. Since the Gulf during the YD was a trough in which the joined Tigris and Euphrates rivers drained, any late glacial sites would now be deeply buried by sediment and under water.

HOLOCENE THERMAL MAXIMUM (HTM)

Over the course of a thousand or more years the YD climate ameliorated and segued into the Holocene Thermal Maximum, a period of some six thousand years during which solar insolation was greater than today, peaking around 9000 ky (COHMAP 1988; Flohn 1991; Robinson 2006:1536). Warmer summer temperatures were accompanied by greater

precipitation. The extent of favorable conditions is seen in the lakes in North Africa and the Arabian Peninsula, as well as marsh conditions in northern Mesopotamia and floods on the Euphrates and Khabur rivers (Courty 1994; Deckers 2004; deMenocal 2000a, b; Ergenzinger 1991; Gremmen 1991; Oates 1976; Oguchi 1998; Sanlaville 1996). Vegetation quickly adapted to the post-YD climate and annual and arboreal plants proliferated and spread across the region (van Zeist 1991). A northward shift of the ITCZ brought summer precipitation to the southern Levant and perhaps to southern Mesopotamia and Iran (COHMAP 1988; El-Moslimany 1986, 1994; Margaritz 1987; Sanlaville 2000: Figs. 69,70). Precipitation may have increased 20-30% (Rossignol-Strick 1999). The climatic conditions were favorable for the first experiments with agriculture (Araus 1998; Hillman 1989, 1996, 2001).

During the HTM a farming economy known as the Pre-pottery Neolithic B (PPNB) developed and people spread again into the steppe zones of the Levant (Perrot 2000). The favorable conditions for agriculture encouraged the nucleation of long-lived, permanent settlements surrounded by fields and pastures for their livestock. This is the first time that the impact of humans on the landscape was noticeably felt (Rollefson 1996), but such disturbances were local and dwarfed by the vast expanses of relatively untouched forest and steppe land (Bar-Yosef 2001).

Following the YD only a small number of Neolithic sites is known from the Jazirah where people mixed hunting and gathering with agriculture (Hole 1997b). This may be a consequence of less intensive archaeological exploration, although regions that have been explored belie this. Unlike the situation in the Levant where there are hundreds of PPNB sites known, they number in the dozens in the Jazirah. It remains to be determined, but is likely, that vegetation was still regenerating from the YD. By the time pottery was in use, about 8000 BP, settlements begin to appear in large numbers.

THE 8.2 KY EVENT

Favorable conditions were abruptly terminated between 8.4-8.0 ky, commonly associated with the world-wide 8.2 ky event (Alley 2003; Dean 2002; Gafenstein 1999; Rohling 2005). “a sudden and simultaneous decrease in rainfall intensity” (Bar-Matthews 1999:91). This sharp spike “occurred in a broad climate anomaly between about 8.6/8.5 and 8.0 ky BP” (Rohling 2005:975). The cold anomaly had about half the amplitude of the YD and may have lasted only 100 years (Alley 1997:484), but was perhaps “superimposed upon a general background of climatic deterioration (Robinson 2006:1537). A prolonged period of deterioration might better explain the abandonment and decline in settlements of all kinds, even in the Mediterranean zone (Perrot 2000). In some ways this event may have been more devastating to humans than the YD in Late Natufian was, because now people were firmly rooted in agriculture and there were too few refugia to sustain them. In the Levant this is known as the *hiatus Palestinian*, although recent discoveries show that it was not a total abandonment (Gopher 1998:207; Sanlaville 1997:25).

Outside the Levant, the arid shock led some to exploit the potential of irrigation in Mesopotamia and others who remained in the semi-arid steppe of northern Mesopotamia to pursue transhumant herding of livestock, with home bases in the wettest rainfall zones close to streams. The 8.2 ky event solidified the dichotomy that continues today between the

northern rain-fed, extensive agriculture with herding and the intensive irrigation-dominated agriculture of the south. From this time onward the cultures of the two regions have been distinctively different despite repeated, but short-term, political unifications.

Sites in the marginal zones were

After the retraction of settlements in the centuries around 8 ky, there was another spurt of growth; by this time hunting and collecting had largely disappeared in favor of farmed products. However, the developments in the north and south differed. Sea level rise in the Persian Gulf and the unstable fluvial conditions on the Mesopotamian plain, coupled with possible seasonal changes in rainfall as a result of the movement of the ITCZ south, created quite different conditions than existed in the Jazirah. In the south, this shift may have altered the seasonal distribution of precipitation from summer to exclusively winter. The effect of this is seen in the abandonment of sites and whole regions beginning around 6.5 ky (Hole 1994). As sea level began to stabilize around 6.0 ky people invested more in irrigation systems and they became largely independent of rainfall, although flooding was a perennial problem. In time these more sophisticated measures led to the growth of small towns and cities.

In the north, where low precipitation had been the limiting factor and winter precipitation the norm, changes were less dramatic. Nevertheless, in the Jazirah there are clear indications of climate change from both geomorphology and settlement distributions. In the late fifth- mid-fourth millennium there are numerous sites, some very large, such as Hamoukar and Tell Brak (Oates 2002; Ur 2002). The existence of these anomalously large sites may be partly explained by favorable climate, as suggested by two sites that we found buried by fluvial action (Hole 1997). Both of these sites lie on the margin of the zone of rain-fed agriculture where today there is no flowing stream. We recovered material from two ash pits dug into sterile soil that were all that remained of the sites (Hole 1997, 2001). The fauna from these pits, including fresh water crabs and mussels, indicate the presence of perennial stream flow. Further evidence of wetter climate is the development of a peat layer in a playa lake in a zone that today lies within the 150 mm isohyet. At the same time as the peat formed there is an increase in oak and gramineae pollen, both suggesting wetter conditions than today (Gremmen 1991:110). Courty and Deckers have both found evidence that flash flooding occurred across the Khabur drainage subsequent to these buried settlements (Courty 1994; Deckers 2004). Other evidence from the same arid region includes the deposition of two meters of silts deposited downstream along the Khabur, and a shift in the course of the river from braided to meandering (Ergenzinger 1991).

While the two buried sites that we discovered were the only sites of the period in our survey area – indeed for the next thousand years -- it is likely that others of the fourth millennium are buried. Moreover, the numerous sites in the wetter part of the region show that settlement increased, implying that it was a time of relative prosperity, although the drier regions were avoided and perhaps reserved for seasonal pasturage (Ur 2002: Fig. 4; Wilkinson 2000: Fig. 8).

The fourth millennium is associated with the Uruk period, a time that saw the first cities emerge in the south. By mid-fourth millennium BC, classic Uruk artifacts are found as far north as southern Anatolia and what appear to have been implanted colonies are found on the

Euphrates (Algaze 1986, 1993; Stein 1999). Despite the apparent vigor of the Uruk people and their ability to use irrigation, the civilization collapsed around 5.0 ky. While the circumstances cannot be easily assessed, it appears that the collapse coincided with a sharp decline in precipitation, which also would have affected Euphrates streamflow. The decline in precipitation coincided with the 5.9 ky ice rafted debris (IRD) cycle, which has a world-wide signal and led to pulses of aridity in the mid-latitudes (Bond 1999; Mensing 2004).

In the Levant there was “an abrupt decline in precipitation around 3500 B.C.E., followed by a short revival for about a century, and then another extreme decline, reaching the lowest peak for the entire Holocene around 3200 B.C.E. This trend continued for about two centuries, turning at around 3000 B. C. E. into a very humid climate” (Issar 2004:90).

EARLY BRONZE AGE – THIRD MILLENNIUM BC

The collapse of the Akkadian Empire at the end of the EBA is well known to coincide with the 4.2 ky event of extreme and prolonged aridity (Weiss 1993). Before this the third millennium saw an unprecedented growth of sites, some attaining the size of towns or cities. Many of these settlements lay in zones that today are unsuited for agriculture because of low precipitation and/or high interannual variability. In our surveys in the arid zone of the Khabur we discovered a large number of EBA sites on landscapes that, for the most part since the EBA, have not seen permanent settlements. Some years ago I surmised that precipitation must have been substantially greater, a proposal that was met with considerable skepticism in the archaeological community (Hole 1997). Such skepticism was warranted in the absence of concrete evidence for precipitation and a general belief that by the EBA people were capable of overcoming climatic variability. We found that early in the third millennium people began to move away from sites on the river to those on the steppe, often far from perennial surface water sources. Many of these sites were walled and of sufficient size and architectural complexity to suggest not only permanence but also political complexity. Curiously, however, we found that these sites were abandoned after some centuries. I inferred, based on such scanty evidence, that there may have been a gradual drying that forced people in the south to move toward the north. I further inferred that accommodating these people in the large sites in the wettest zone put additional stress on the landscape such that when the abrupt pulse of aridity came, the people could not adapt and “collapse” followed (Hole 1997).

There are, of course, counter-arguments. For one thing the spread of walled settlements on the steppe was certainly related to the commodification of wool. Market incentive or imperial directive may have encouraged unwise intensive utilization of the steppe (Kouchoulos 1998). Nevertheless, it is not conceivable that settlements with thousands of people and livestock could have existed without either dependable agriculture or fresh water. Since I wrote this scenario we have learned that effective precipitation in the earlier part of the third millennium was the highest in all of the Holocene and settlements extended far beyond the 200mm isohyet (Issar 2004:101,116). Issar and Zohar refer to a number of proxy records that provide “abundant evidence for a cold climate over the entire northern hemisphere during the first half of the third millennium B.C.E....Precipitation during this period reached at least that of the Chalcolithic period and exceeded the peaks of precipitation of all the historical periods to follow” (Issar 2004:100-101; Robinson 2006:1537). One should also consider that cooler

temperatures might have lessened evaporation, thereby increasing available ground water for the germination and development of cereal grain.

While we do not have complete archaeological evidence for the region, several surveys, based on reconnaissance of sites, mostly in the wetter zones, dated by the pottery on the surface, give substantially the same results: there was a spike in the third millennium in both numbers of sites and sizes of sites (Ur 2002: Fig. 4; Wilkinson 2000: Fig. 8). Unfortunately, many of these data are not sufficient to inform on how rapidly population increased or when particular sites were abandoned. The advantage of our survey in the arid zone is that we can chart such changes more readily because there is no confounding effect of either earlier or later occupation.

THE 4.2ky EVENT

The 4.2 ky event is now recognized world-wide. An “extraordinary and persistent drought occurred on all Northern Hemisphere continents within a century of two of 4.2 ka, amounting to a hemisphere-wide megadrought far surpassing the droughts of the past millennium in severity and/or duration” (Booth 2005). Nevertheless while there are still some differences among archaeologists as to its impact on particular sites, there is general agreement that most sites were much reduced in size. Weiss (2001) believes he has detected the “moment” when the building of a palace, at Tell Leilan was abruptly halted, denoting the termination of Akkadian activity there.

Aridity is thought to have continued for some 200 years, after which there is a noticeable resumption of life at most sites in the better watered zones, but we have found no such evidence in the marginal zones. In fact, settlement did not resume here for another thousand years. It is interesting that periods of occupation occur on cycles of 1000-1500 years, suggesting possible correspondence with the Dansgaard/Oeschger cycles, one of which is at 4.2ky (Bond 1997; Cullen 2002:335; Hole 1997; Leuschner 2000). The limited evidence that we have from our surveys suggests that each cycle of settlement thereafter was of lower amplitude; that is, sites were smaller and shorter-lived.

CONCLUSIONS

Lessons to be learned from archaeology and history are how dependent people in the Near East are on precipitation and that periods of aridity have repeatedly changed the course of history. In fact, few civilizations have endured without fundamental changes for more than a few hundred years. As evidence of climate change becomes more detailed it appears that many events had world-wide or broadly regional impact on human activities. The periodicity seen in the Khabur resembles that of the D/O cycles, but a causal relationship with human activities remains to be determined (Andrews 2006). We need precise knowledge of climates, based not on regional or world-wide models, but local events (Mayewski 2004:252). There are a number of questions for paleoclimatologists that would be of great value to archaeologists and historians. How did climate vary over the region at any given time? Can the various proxies be synchronized to provide human-scale (spatial and temporal) images of climate that can be related to archaeology and history? What were the climatic effects of the monsoon system during the HTM on the different parts of the Near East?

Archaeologists and historians also have important issues to resolve. Unfortunately the pace of research on the human past is much slower than that of climatology. Archaeologists have been slow to recognize the possible impacts of climate on the cultures they study and have typically not focused their research on critical times and places. To the extent that it is possible this imbalance needs to be redressed. Archaeologists need to design research that focuses on sites and regions that can shed light on climate and human interactions. They also need to develop better proxies, such as can be derived from botanical remains, for estimating past environmental conditions. They must also pay much more attention to securing accurate chronologies. In part these matters can be rectified by designing field work to recover the data, but also engaging in collaborative research with scientists in ancillary fields. With true collaboration the important questions can be asked and solutions sought. For example, much progress can be achieved through careful study of the geomorphology and micromorphology of archaeological sites and their settings (Courty 1994; Deckers 2004; Goldberg 1993, 1994; Rosen 1995; Wilkinson 1995).

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WATER, LIFE AND CIVILISATION - A 5-YEAR MULTIDISCIPLINARY PROJECT

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ABSTRACT

With funding from the Leverhulme Trust, a multi-disciplinary team from the University of Reading aims to assess the changes in the hydrological climate in the MENA region and its impact of human communities. The project has two levels. First the development and evaluation of a climate model for the MENA region as a whole, together with a study of its implications for past, present and future human settlement. Second, a detailed case study of the interplay between climate, water and human society from 20,000 BC to AD2100 in the Jordan Valley. This will involve the development of a hydrological model, palaeoenvironmental studies of landscape and vegetation change, archaeological studies of human settlement, diet health and water management, and an examination of current issues regarding water usage in the context of industrial, agricultural and tourist development.

INTRODUCTION

The inter-play between climate and water availability has been fundamental to human activities in the past and will continue to be so into the future, nowhere more so than in the semi-arid regions of Middle East and North Africa (MENA). It is in the great river valleys of this region – the Jordan, Euphrates, Nile and Indus – that the ancient civilisations arose, while the plight of this region under a changing climatic and hydrological regime is central to global ecology, economics and politics today.

The one resource at the centre of all such past and present activity is water, its status changing from a natural resource to a cultural commodity and having now become a resource at the centre of political tension, in some circumstances provoking conflict, and in others international cooperation.

The Water, Life and Civilisation project aims to explore the past, present and future relationships between water and human settlement in the MENA region, with a specific focus on the Jordan valley. The project has five component parts consisting of two models, one for climate and one for hydrology, and studies concerning palaeoenvironments, the history of human settlement, and the current and future patterns of land use.

THE COMPONENTS OF THE WLC PROJECT

Climate and Hydrological Modelling

The climate modeling sub-project aims to predict past and future annual and seasonal changes in climate for the MENA region using climate model simulations, and to evaluate these simulations using climate proxy, archaeological and geographical data. The climate model output will be used to drive a hydrological model, which will be used to predict the spatial and temporal variations in water flow regime and salinity of the Jordan River in the past and

future. In order to provide data at a fine enough resolution for the hydrological modeling, a version of the Hadley Centre regional climate model (RCM), *Precis*, has been implemented for the MENA region. Some preliminary results from this model are shown in Figure 1, which superposes rain gauge data onto model simulations of precipitation rate. It can be seen that there is reasonable agreement between the model and observations.

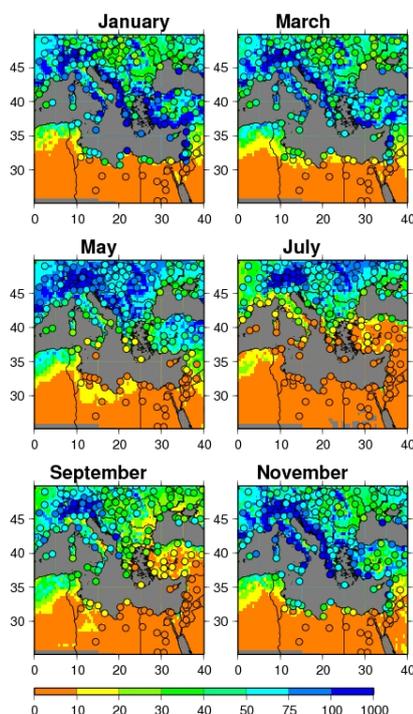


Figure 4. The seasonal cycle in rainfall as simulated by the *Precis* regional model. The coloured circles represent rain gauge data (taken from the Global Historical Climate Network data archive)

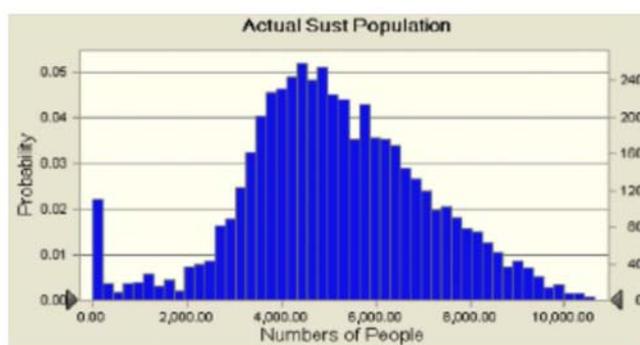


Figure 5. Probability distribution of population levels in Jawa approximately 3500BC.

In the first year of WLC, a new approach to the hydrological modelling of archaeological sites has been developed. This method links water resource regimes with sustainable population levels. Uncertainties in the input data (for example historical rainfall) are accommodated using a Monte Carlo method and the result of the modelling is a probability distribution of population levels. This method was applied to the pre-historic population of Jawa in the northern part of Jordan. Figure 2 shows the sustainable population approximately 3500BC

based on a hydrological model driven by rainfall from climate model simulations.

Palaeoenvironment Studies

The aim of the palaeoenvironment component of WLC is to reconstruct prehistoric, historic and modern landscapes to interpret river flow regimes (and hence water table, fluvial power and flow dynamics), sedimentary deposition and vegetation history of the Jordan Valley area. The palaeoenvironmental evidence will be used to test the climate and hydrological models, and then refine these models to produce more accurate predictions for the past, present and future.

Preparatory fieldwork has established that there are extensive Dead Sea travertine sequences cropping out between 350 and 178m below sea level (see for example Figure 3). The extent of these thick (10m+) sequences indicates that they were deposited rapidly, preserving a very high resolution sequence of climatic events.



Figure 6. A travertine deposit close to Ma'an in the southern part of the Jordan valley

In addition, field studies of historical and pre-historical sites have been undertaken. Several Neolithic archaeological sites (for example Beidha) have been found to have sequences of materials preserved near to the settlements, which could potentially provide climatic data relating to the origin of settlements and the onset of farming. Historical sites such as the Roman city of Jerash, have carbonate deposits on water channels, mills and reservoirs, which are well preserved and will provide information on water availability, sources and compositions for these cities.

The History of Human Settlement

This history of human settlement in the MENA region will be explored in the archaeology component of WLC. The specific aims are to develop our understanding of the history of human settlement within the Jordan Valley, of the methods used to manage water supply, and of the changes in human health and diet from pre-farming to the modern day. Interpretation of the archaeological evidence will be conducted in light of the output from the climatic and hydrological models and the palaeoenvironmental studies.

The research programme for archaeology has four elements: improving chronologies for prehistoric settlement; investigating human diet and health; inferring irrigation from archaeobotanical material; and exploring water management via analysis of structural remains such as aqueducts, cisterns and dams.



Figure 7. Archaeological remains at Wadi Faynan.

A variety of methods are being used. These include case studies of key archaeological sites such as Wadi Faynan (see Figure 4) and Jawa in collaboration with the hydrology and palaeoenvironment projects; experimental crop-growing studies in collaboration with the development studies project; and isotopic analysis of skeletal remains.

Development Studies

The final component of WLC, development studies, will investigate the current and future interactions between industrial, agricultural and tourism development and their impact on water usage and supply. This work will be undertaken in the context of new schemes for water management being introduced by the Jordanian Government and predictions from the climate-hydrological model. Studies will also be undertaken for how the use of sewage and other water waste products can be used for agricultural irrigation. The project focuses on two major aspects of contemporary water use: (1) The use of treated water for agriculture (see Figure 5) and (2) the urban situation (see Figure 6).

SUMMARY AND CONCLUSIONS

To summarise: the WLC project aims to provide an understanding of the longterm interaction between climate change, hydrological regimes and human activity. WLC has five component sub-projects, which are collaborating closely to achieve these aims. The research consists of both large-scale studies of climate change in the whole MENA region and detailed case studies of archaeological sites such as Wadi Faynan, Jawa and Jerash.



Figure 8. Soil sampling in the Zarqa River valley. People in photograph: From left - Gemma Carr, Khalil Jamjoum, Sameeh Nuimat and land owner.



Figure 9. A view of Amman. A study of water usage in Amman will be one of the major components of the WLC development project.

LONG-RANGE FORECASTING AND THE SCIENTIFIC BACKGROUND TO JOSEPH'S INTERPRETATION OF PHARAOH'S DREAMS

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ABSTRACT

Long-range forecasting is today a major area of climate research. Such forecasts affect socio-economic planning in many fields of activity. There are essentially two approaches to long-range forecasting: one is based on solving the equations that govern atmospheric and ocean dynamics, the other on the statistical properties of past climate records. The present talk is based on the latter, statistical approach.

Joseph's interpretation of Pharaoh's dreams provides a striking example of long-range planning based on a climate forecast. Joseph interpreted the two dreams as a forecast for seven years of plenty, followed by seven of famine. Based on this forecast, he proposed to Pharaoh a plan for running the agriculture and economy of Egypt. It is not clear from the Biblical story why Pharaoh trusted Joseph's forecast and appointed him to implement the plan.

Our answer to this question is based on ancient and medieval Egypt's being entirely dependent on the Nile River's seasonal flooding: when the highest water levels did not cover the arable areas of the river valley, crops were insufficient to feed the population. When successive years of hunger weakened the economy and the state, change of rulers could, and sometimes did ensue. Extreme examples were the fall of the Old Kingdom in 2185 B.C. and the Fatimid conquest of Egypt in 969 A.D.

Hence the Egyptians measured the high-water mark of the Nile River for over 5000 years, using different tools. The most advanced of these tools was the nilometer; typical nilometers appear in several mosaics from the Roman and Byzantine period around the Mediterranean, such as the "Nile Festival" mosaic in Zippori (Upper Galilee), Fig. 1. The measurements had a twofold purpose: first to set the annual taxes, which were a function of the high-water mark, for obvious reasons; and second, to provide information for water management, with a view to reduce drought damage.

Our analysis of high- and low-water levels for 622–1922 A.D. shows that oscillations with a period of several years occur, with a 7-year oscillation being dominant. We suspect that the origin of this 7-year swing lies in the same periodicity being present in the North Atlantic's sea-surface temperatures and sea-level pressures. This North Atlantic Oscillation affects the climate of Europe, North America and the Middle East, and might be the ultimate reason for Joseph's successful climate forecast.



Figure 1. "Nile River Festival" -- The picture shows a Byzantine-period (5th century) mosaic from Sepphoris (today Zippori), in the Galilee (Northern Israel). It shows a man clambering to carve on a column ("nilometer") the level of "plenitude" (i.e., the mean high-water mark), namely 17 cubits ("IZ" in the Greek digits used at that time); at this level the irrigation ditches were opened and the Nile festival began. The Zippori mosaic seems to be the best-preserved one among several depictions of this Festival. Photographs taken and processed by Yigal Feliks.

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