Conference

Climate and Society in Ancient Worlds
Diversity in Collapse and Resilience

Brussels, May 22-24, 2019

Organizers:
P. Erdkamp, Vrije Universiteit Brussel
J.G. Manning, Yale University
K. Verboven, Universiteit Gent

Location:
Wednesday and Thursday: Royal Flemish Academy of Belgium for Science and the Arts, Palace of the Academies, Hertogstraat 1, 1000 Brussels. http://www.kvab.be/en/contact

Friday: Vrije Universiteit Brussel, Campus Etterbeek, Pleinlaan 2, 1050 Brussels. Q-building. Room QD.
http://www.vub.ac.be/sites/vub/files/campus/plans_VUB_Etterbeek_NL_2015_nieuwe_layout.pdf

No registration fee. Registration: please email to perdkamp@vub.be

Program

Day 1. Morning: 9:15-13:00 h.		
Erdkamp, Paul & Koenraad Verboven	Vrije Universiteit Brussel / Universiteit Gent	Welcome
Heinrich, Frits & Annette Hansen	Vrije Universiteit Brussel / Rijksuniversiteit Groningen	A hard row to hoe. Climate change from the crop perspective
Malanima, Paolo		Population and climate in Italy 1650-1913
Lee, Harry F.	Chinese University of Hong Kong	Making sense of the climate-war nexus in history
Maher, Lisa A.	University of California, Berkeley	Becoming Neolithic or Being a Hunter-Gatherer? Framing human-environment interactions at the origins of agriculture through a longue durée perspective
Day 1. Afternoon: 14:00-18:00 h.		
Hafner, Albert, and Caroline Heitz	Universität Bern	Concepts of collapse, resilience and mobility in prehistoric archaeology
Ertsen, Maurits	Delft University of Technology	Gone water does mill again. Comparing How Two Irrigation-Based Societies Dealt with Climate
Moreno García, Juan Carlos	Université Paris-Sorbonne Paris IV	Climate, state building and political change in Egypt during the Early Bronze Age

De Graef, Katrien	Universiteit Gent	Chronicle of a Collapse Foretold. The End of the First Dynasty of Babylon.
Weiss, Harvey	Yale University	Global megadrought, societal collapse and resilience at 4.2-3.9 ka BP
Day II. Morming: 9:30-13:00 h.		
Weiberg, Erika, & Martin Finné	Uppsala University	Contextualizing climate variability in Late Bronze Age Peloponnese (Greece)
Brysbaert, Ann, & Riia Timonen	Universiteit Leiden	Saving up for a rainy day? Climate events, human-induced processes, and their potential effects on people's coping strategies in the Late Bronze Age Mycenaean Argive Plain, Greece
Bonnier, Anton & Martin Finné	Uppsala University	Peloponnesian land-use patterns, settlement dynamics and climate variability in the first millennium BC
Manning, J.G.	Yale University	Volcanoes, Nile variability and the course of Egyptian history. The historical and human dimension of climate change
Day II. Afternoon: 14:00-17:30 h.		
Franconi, Tyler V.	University of Alberta	The Environmental Imperialism of the Roman Empire in northwestern Europe
Bannon, Cynthia	Indiana University, Bloomington	Seasonal Drought on Roman Rivers: Transport v. Irrigation
McDonald, Brandon	University of Oxford	The Antonine Crisis: Climate change as a trigger for epidemiological and economic turmoil
Day III. Morning: 9:30-13:00 h.		
Erdkamp, Paul	Vrije Universiteit Brussel	Climate change and the productive landscape in the Mediterranean in the Roman period
Kelly, Paul	King's College London	Risks for farming families in the Roman Empire
Marzano, Annalisa	University of Reading	[Climate change and wine cultivation in Italy]
Van Limbergen, Dimitri, & Wim De Clercq	Universiteit Gent	Viticulture as a climate proxy for the Roman world: evidence and problems
Day III. Afternoon: 14:00-17:30 h.		
Daems, Dries, et al.	Katholieke Universiteit Leuven	The social metabolism of past societies. A new approach to environmental changes and societal responses in the territory of Sagalassos (Turkey)
Maranzana, Paolo	University of Michigan	Resilience and adaptation at the end of Antiquity: an evaluation of the impact of climate change in Late Roman Central Anatolia
Xoplaki, Elena, et al.	Justus-Liebig-University Giessen	Late Antiquity hydrological changes: spatio-temporal characteristics and socio-economic impacts in the Central and Eastern Mediterranean
Horden, Peregrine	Royal Holloway, University of London	Climate, resilience and disease in the post-Roman north west

Abstracts (in order of program)

Frits Heinrich & Annette Hansen

A hard row to hoe. Climate change from the crop perspective.

Over the past years the potential impact of climate change on past societies has become a topic that is increasingly applied to narratives on economic history. Some scholars see it as a determinant of economic growth and contraction or even use it to explain the rise and fall of empires and civilizations. Such models argue that climate change affects agricultural output, which it, under certain circumstances, indeed can do. An important element that is currently underrepresented and oversimplified in the debate, is the effect of climate change on plant growth, especially of cultivated plants (i.e. crops). This lacuna is problematic as agricultural output is obviously strongly related to plant growth. This chapter seeks to fill this void by presenting a comprehensive overview and model of the effects of climatic changes on plant growth, both from the perspective of plant biology and crop cultivation.

Paolo Malanima

Population and climate in Italy 1650-1913

Demographic data are scanty for ancient Italy. We know how even the topic of the Italian population at the time of Augustus is still debated. Much more precise is our knowledge of the Italian demography from the seventeenth century on. Since in Italy the start of demographic transition occurred relatively late, rich data on population, births, deaths and marriages from about 1650 may, if not replace, at least suggest the working of a pre-modern demographic system. Moreover, for the eighteenth century we can avail, for some areas of northern Italy, of precise data, albeit discontinuous, on temperature and rain. This data contributes to specify the relationship between climatic events and rates of births and deaths.

Harry F. Lee

Making sense of the climate-war nexus in history

Are wars really caused by climate change in history? Even though there are increasing number of studies (both quantitative and qualitative) illustrating the climate-war nexus in pre-industrial societies, opposing voices are always around. In this paper, I try to summarize the current debate of the climate-war nexus to reveal its controversies. Also, a simple conceptual framework is proposed to resolve those controversies. The ultimate goal of this paper is to answer in what sense wars are caused by climate change in history. I hope that the debate of the climate-war nexus could be moved away from yes/no conception, with the multiple dimensions of wars thoroughly considered.

Lisa A. Maher

Becoming Neolithic or Being a Hunter-Gatherer? Framing human-environment interactions at the origins of agriculture through a longue durée perspective

Searching for the origin points of major cultural revolutions and transitions has long been a driver of archaeological research, yet led to research focused on perceived boundaries, rather than continuity. Research into the origins of so-called modern human behavior, the origins of social complexity, the earliest domesticates, among others, all focus on defining moments of change that may be undetectable in the archaeological record. Perhaps some of the most enduring archaeological

questions revolve around the ‘origins of agriculture’. Here, I explore changing historical conceptions of the ‘origins of agriculture’ in Southwest Asia in archaeological discourse and how, through the lens of the longue durée, we can trace aspects of material culture, human action, and complex human-landscape dynamics in deep time. Using examples from the Epipalaeolithic of eastern Jordan, I address current debates on Neolithization by exploring the implications of perspectives that focus on ‘becoming’ Neolithic and ‘being’ a hunter-gatherer.

To-date, a variety of `Neolithization' pathways have been developed to explain the adaptations that characterized the emergence of Neolithic life, sedentary occupations, and agriculture, now widely argued to appear during the Early Epipaleolithic (ca. 23 ka cal BP). The site of Kharaneh IV, among others in the Azraq Basin, provides evidence for substantial aggregations of human groups who were linked into wide-ranging regional networks of interaction and exchange. These intensive occupations were supported by extensive wetlands, lakes and a well-vegetated environment—conditions very different from that of today—that likely buffered populations here against adverse climatic oscillations during the LGM and provided a stable late glacial refugium for human groups. Thus, the Azraq Basin appears to have been a much more stable and less marginal environment for human groups during the turbulent climatic history of the late Quaternary. Integrating multiple material cultural and environmental datasets, I explore some of the strategies of these hunter-gatherer groups that resulted in changes in settlement, subsistence and interaction and, in some areas, the occupation of substantial aggregation sites. Aggregation sites like Kharaneh IV may have served as nodes of interaction in the landscape; where groups from the region congregated, leaving evidence for repeated and prolonged occupation and a rich record of hunter-gatherer lifeways. Indeed, environmental evidence from Kharaneh IV emphases the importance of the wetlands as an under-recognized reliable resource in otherwise risky periods of landscape change, and may suggest an unexpected `Neolithization' pathway. Through this nuanced perspective of human-environment dynamics, I discuss different scales of these lifeways; from the ‘ethnographic’ lens identifying individual behaviors in the past, to the longue durée of material culture trends. This multi-scalar perspective gives insights into how we construct cultural boundaries and understand change during the ‘origins of agriculture’.

Albert Hafner and Caroline Heitz

Concepts of collapse, resilience and mobility in prehistoric archaeology

The topic of societal collapse was introduced to archaeological and anthropological sciences from different directions in the late 1980ies. In the same measure as societies of the early 21st century got aware of global change the concept of past societal collapse was popularized. This can be shown exemplarily through the hype around books of Jared Diamond, reaching extremely large readership. Archaeology – and mainly prehistoric archaeology – is a science, which is used to work with large times scales. Contributions to climate change research therefore offer chances to get involved in research topics of societal relevance. If archaeologists can show that during long periods of the Holocene human societies have been vulnerable and were forced to be adaptive to new environmental situations this may also change the view of our own, comparable quite static societies of the 21st century.

The scheduled chapter will focus on the following topics:

Review of how the concept of collapse and later on the concept of resilience was introduced into archaeological and anthropological sciences: this section will lead to the topic and give a critical

overview on different methodological approaches. Further we will bring in thoughts on mobility and entanglements of prehistoric societies.
Three cases studies will structure the chapter. We will focus on agrarian societies, we will not deal with hunter-gatherer societies. The chronological frame covers societies from the Early Neolithic to the Bronze Age, thus large parts of the Holocene:
Rapid climate change as trigger and spreading of Neolithisation: this chapter will focus on two climate events in the early Holocene. The rapid warming at the end of the glaciation period around 12'000 years ago and the 8.2k event which is seen by some researchers as a collapse situation. There is a large consensus in science that the emergence of farming was triggered by climate change. Especially the 8.2k event will be critically reviewed, since this situation is much less clear and debated.
Collapse of the Neolithic Linear Band ceramic (LBK) system: LBK farming is the first phase of agrarian economy in central Europe starting around 5500 BC. Some researchers see a catastrophic end around 5000 BC due to a few examples of mass graves following massacres (Talheim, Kilianstätten, Asparn/Schletz) and enigmatic structures with human remains (Herxheim) as well as a presumed reduction of settlement activities.
Wetland settlements in lakes and bogs of the Alpine Space (4300-800 BC): Intensive research allows to present examples of collapsing settlement activities related to Holocene climate change. Well-researched sites with complete information on size, development and chronology deliver the best examples. Mainly rising lake levels following Holocene cooling events are seen as a factor for the temporal interruption of settlement activities near lakeshores. Recurring flooding events which transformed settlement areas for decades or centuries into submerged landscapes affected highly mobile agrarian societies severely but did not lead to any form of societal collapse. These populations clearly showed pronounced capabilities to adapt to challenging environmental situations. Their level of complexity allowed them to respond to climate related impacts and to move to new settlement areas. Flood events are seen as the major factor of turning down settlement activities. Their resilience towards these environmental impacts make the wetland settlements in lakes and bogs of the Alpine Space a special example for the resilience of early agrarian societies.
The final part of the chapter will be a synthesis on the topic of collapse and resilience based on our case studies and bring in aspects of mobility and entanglements of prehistoric agrarian societies. In this chapter we will discuss results from an ongoing Swiss National Science funded project („Mobilities, entanglements and transformations in Neolithic Societies on the Swiss Plateau").

Maurits Ertsen

Gone water does mill again. Comparing How Two Irrigation-Based Societies Dealt with Climate

Emerging societal complexity is an important theme within archaeology. Water systems – especially irrigation – enabled the production of the food to support the larger population associated with complex societies. In response to climatic conditions and/or changing climates, controlled water provision through irrigation would have created relatively stable conditions in ancient Mesopotamia, Egypt, India, China, Mexico and Peru. Having said that, the archaeological record is also overflowing with examples of irrigation-based societies collapsing, for different reasons, climate change being one of them. In this chapter, I propose to look anew at this perceived close relation between irrigation, civilization and climate through a comparison of two irrigation-based societies. Within archaeology's long term perspective on larger spatial scales and longer time scales, it remains challenging how social

complexity could emerge from continuous interactions between humans and irrigated landscapes. How did our ancestors move from their today to their future, in the small steps that produced their reality? I propose a modelling method to answer that question.

Ancient Mesopotamia (between the 4th and 2nd Millennium) relates to one of the earlier – and arguable more famous – proposals on the relationship between human societies, water and climate: Wittfogel's Oriental Despotism. State arrangements would result from societies managing their hydrological endowments. With water distributed equally, like in areas with ample rainfall, political power was distributed as well. With skewed water distribution, like Mesopotamia, political power was for those who controlled the water. Expanding irrigation infrastructure would have created increased state control over people and environment.

Wittfogel's massive control suggests that Mesopotamian irrigation was realized in a relatively short time period. There is growing evidence, however, that Mesopotamian irrigation development was a gradual creation of anthropogenic irrigated landscapes. Over centuries, elites would have grown from controlling agricultural trade, which would have been the nexus for state formation. Furthermore, Wittfogel claims Mesopotamia being dry when cities emerged.

However, the early Mesopotamian plains were tidally influenced marshes with levees running through. Settlement on levees allowed agriculture on the high soils and resource exploitation in the low marshes. Over time, sea level decline created drier conditions for communities already there, which would have led to a transformation towards irrigated cereal-based urban societies of Mesopotamia.

My second setting moves out of the suggested time frame. In the Phoenix basin (modern Arizona) between 0AD and 1450AD, Hohokam culture is typically seen as an irrigation-based society that did not become a complex society. The Hohokam developed monumental architecture and extensive hydraulic infrastructure, but no elitist state structures. Furthermore, Hohokam is a popular symbol for the risk associated with relying on and overstressing a single source of food production. The Hohokam period is generally divided into Pioneer, Colonial, Sedentary and Classic periods. As the name suggests, the Classic period would be the core period of a flourishing Hohokam civilization, but flourishing may be a little optimistic. A drought in the late 1000s-early 1100s coincides with the turn from Sedentary to Early Classic period. At this time, abandonment of large tracts outside the major river valleys and a concentration of settlement closer to the riverine habitats seem to have occurred. A second drought period, between 1275 and 1350, would have had the highest incidence of both droughts and floods, compared to earlier periods. This would have put stress on cooperative efforts – why invest time in repairing a system after a flood when it did not pay off the last time because of drought? There is also evidence that many people moved out into the desert during relatively wet periods only to come back later with recurring dry conditions. This could have added further strain on any coalition structures in the late Classic. As such, the Hohokam might not be a society that overstressed its resources, but an example of how difficult it is for a society to deal with risks, as meanings of risks change as much as the environment itself.

The comparison allows me to explain how I develop a model-based, action-oriented methodology to study the development of social complexity, strongly rooted in theoretical work, especially actor-network theory.4 Mesopotamia's and Hohokam's anthropogenic irrigated landscapes emerged from short-term activities with massive long term effects. To get a grip on this, I study those settings as being performed.5 In the performance of a diversity of agencies, we encounter active

constructions of actor-networks. My agent-based modelling simulates irrigated landscapes through agencies of different kinds, taking properly into account the complex relations between human actions and the social-material contexts in irrigation landscapes, will open the door to study the meaning of matter/nature in the development of social complexity by including the following two dimensions: 1) how negotiations between humans and non-humans co-shaped ancient practices and landscapes and 2) how we in the present chose to study those practices and landscapes, including how we conceptualize the material.

Juan Carlos Moreno Garcia

Climate, state building and political change in Egypt during the Early Bronze Age: a direct relation?

The beginning and the end of the first period of political unification in Egypt (roughly, from 3100 to 2150 BCE) has been traditionally related to climatic events. In the first case, increasing arid conditions in NE Africa and the Eastern Sahara would have made permanent occupation impossible in former steppe areas, thus forcing populations to concentrate and settle in the Nile Valley and inducing sedentary lifestyles centered in agriculture, incipient urbanism, specialization of labor and the emergence of the state. As for the second case, climatic change around 2200 BCE would have had catastrophic effects on irrigation and agricultural production, leading to the collapse of the tax system and the ruin of the monarchy itself. However, recent archaeological research as well as more sophisticated analysis of written sources and of the ideological codes implicit in them reveal situations much more nuanced. While aridification certainly affected Near Eastern societies in some periods during the fourth and third millennium BCE, crude climatic determinism is not certainly tenable as social and political change depended on a more complex set of circumstances. It seems that increasing tax pressure had a negative impact on the populations living in Egypt and in certain areas of Mesopotamia. However, at the same time, the demand of the states in these areas probably induced economic specialization that turned some populations towards more mobile lifestyles as providers of particular products (pastoralism, search for minerals, fishing, etc.). Such move is particularly visible in some Egyptian inscriptions around 2100 BCE. This may explain why some areas thrived while others abandoned their former sedentary lifestyles to turn themselves to more mobile ones. In fact, mobility induced a broad diffusion of techniques (metallurgy, etc.) and ideas and promoted an expansion of exchanges over vast areas, from Central Asia to NE Africa. The consequences are also visible in the political sphere, when centralization of power could no longer be easily restored around 2000 BCE and when negotiation, as well as more flexible forms of organization of authority, became common in the Nile Valley and in the Near East. So, this paper intends to analyze all these changes happened during the Early Bronze Age and to test the validity and limits of climatic change as a driver of change in this period in Egypt and in neighboring areas.

Katrien De Graef

Chronicle of a Collapse Foretold. The End of the First Dynasty of Babylon

Late 3rd to mid-2nd millennium BC southern Mesopotamia is characterized by a sequence of relatively short-lived territorial states based in respectively Akkad, Ur, Isin, Larsa and Babylon. It had been assumed that climate change in Upper Mesopotamia resulting in a global drought event around 2200 BC forced the collapse of the Akkadian kingdom, but this has recently been convincingly refuted (Dornauer 2017). The same goes for the argument that climate change at the end of the 3rd millennium

BC caused Amorites to migrate into Mesopotamia which, in combination with overcultivation resulting in salinization and soil nutrient exhaustion, caused the fall of the Ur III dynasty (Powell 1985, Yoffee 2010). Especially in this last case, it is clear that the main reason for the Ur collapse was not climatological but a combination of internal crises, causing a massive inflation, and the invasion of the Elamites from the East who were able to attack the state in its heart and destroy its capital (a.o. Gomi 1984, Lafont 1995).

In each case, it took the victorious dynasty only little time to get the state back on track. One could even argue that these successive dynasties were, on a state-organizational level, variations on the same theme, albeit with their own capital and slightly varying socio-cultural characteristics. In any case, the rise and fall of these successive dynasties did not involve structural crises leading to a thorough reconfiguration or shift in the mode of regulation. This was however the case after the fall of Babylon in the middle of the 2nd millennium BC. Notwithstanding the fact that the so-called "Dark Age" of two centuries following the collapse of the 1st Dynasty of Babylon was certainly less dark that initially thought, as is shown by tablets partially bridging this gap, from Tell Muḥammad (Al-Ubaid 1983) as well as the recently published tablets from the Sealand Dynasty (Dalley 2009, Boivin 2017), including the finds from the recent excavations in Tell Tell Khaiber (Campell et al. 2017), the Babylonian to Kassite transition clearly involved a drastic restructuring of social institutions.

In this paper, I will go into a full consideration of the various — often interrelated — causes that led eventually to the collapse of the first dynasty of Babylon. My working hypothesis is that the interrelation between the franchise system applied by the state in order to outsource its economic activities and the geographical evolution of the fluvial system of the Euphrates compromising a hydrological balance already fragile especially in the south, led to an ever-increasing weakening of Babylonian state power. This enabled the establishing of autonomous military communities in the countryside that in the end will provide the Hittites free passage to raid Babylon.

At the dawn of the 2nd millennium BC, the redistributive economy highly controlled by the state is gradually replaced by a franchise system in which the state outsourced its economic activities to individual contractors and entrepreneurs. As such, the state divested itself of the immediate supervision of economic operations and maintenance of the labour force. The contractors and entrepreneurs who were entrusted with these tasks, were obliged to pay the state a specified amount of goods in kind or an equivalent value in silver. However, due to poor harvests or warfare, in combination with the often high-risk investments these individuals were involved in, they were not able to pay the stipulated annual dues, and arrears accrued, which in the end had to be remitted by the state as it was dependent on these contractors and entrepreneurs for its economic activities. The franchise system created the conditions that led time after time to increased indebtedness and social imbalance which had to be reversed when economic relations were distorted beyond a socially tolerable limit. This was done by the rulers through the promulgation of royal decrees cancelling the arrears and outstanding debts in order to prevent the economy from complete stagnation.

The situation became even more precarious when, only 15 years after Hammurabi established the Babylonian state, revolts broke out in the South during the reign of his son and successor Samsu-luna, leading eventually to the loss of the South by the end of his reign. The difficulties in the south were probably due to the increasing threat of floods in northern Babylonia which Samsu-iluna tried to prevent by digging a canal to drain the swollen waters of the Euphrates to the depression of the present-day Lake Habbaniyah, but in doing so caused a shortage in the water supply in the South,

resulting in poor harvests, famine and eventually revolts (Cole, Gasche 1998, Charpin 2002, Gasche, Tanret, Cole, Verhoeven 2002). Age-old urban centres such as Ur, Uruk, Larsa and Nippur could no longer be supported and settlement was reduced to dispersed villages, causing a massive migration to the north and a, at least partly, abandonment of the south for a long period, as shown by archaeological prospections revealing a complete absence of late Old Babylonian material there (Gasche 1989).

The abandonment of the South not only led to a substantial loss of royal lands and consequently production, but also caused a massive migration of economic refugees to the northern area still under Babylonian control. The fact that these refugees did not return to their cities implies that the state was at the time not able to cope with the hydrological disturbances — whereas the Kassites would later solve the problem by digging a large canal out of the Tigris to water the Nippur area. Although the Babylonian state continued to exist for a little more than a century in the northern area between Dilbat and Sippar, where the hydrological situation was much better, it was bound to collapse. Whereas the periodical cancellations of the outstanding debts prevented the economy from complete stagnation and collapse, it was only a short-term solution. In fact, the hydrological interventions of the later Babylonian rulers, diverting waters, can also been seen as relatively short-term solutions, not solving the problem and resulting in the loss of the South and the shrinking of the state. The Babylonian rulers temporarily counteracted the symptoms but were never able to solve the causes of the failing economic and hydrological systems. After the structural crisis during Samsuiluna's reign, causing a massive migration to the north and a, at least partly, abandonment of the south for a long period, internal crises kept accumulating in the north, leading up eventually to an ultimate crisis in the middle of the second millennium BC. One could argue that the collapse actually started under Samsu-iluna and lasted more than a century.

Harvey Weiss

Global megadrought, societal collapse and resilience at 4.2-3.9 ka BP

Decadal to century-scale megadroughts are a recently discovered but now well-documented feature of the Holocene. A major and much-discussed example is the abrupt global megadrought and cooling at ca. 4.2-3.9 ka BP (2200-1900 BC), i.e., the 4.2 ka BP megadrought. Data for this megadrought are derived from analyses of lake and marine sediments, glacial and speleothem cores, and tree-rings. In the eastern hemisphere, these high-resolution proxy records extend across the Mediterranean to east Asia and Australia. The megadrought signal also crossed the African continent, from Algeria and Egypt to South Africa and from the Horn of Africa to the central Sahara and the Gulf of Guinea. In the western hemisphere, the proxy records extend from Greenland and Iceland to the Caribbean, across North America to the Canadian Yukon, and down the western coast of South America from Peru to Patagonia and the Antarctic (Weiss 2015; Zanchetta 2016). Lower resolution proxy data, retrieved by earlier researchers, either failed to note this megadrought or dated it so loosely that synchronous events were obscured. The newer high-resolution data are, however, virtually impossible to miss or disregard, such that the 4.2 ka BP megadrought has become the focus of volumes of symposia and research conferences annually, alongside scores of journal articles. For reasons yet unknown, the major global monsoon and ocean-atmosphere circulation systems were deflected or weakened synchronously at 4.2 ka BP, causing major, century-scale precipitation disruptions and failures. The most notable of these global deflections, and the most regionally extensive, are also the most highly resolved in paleoclimate proxy records and are themselves linked to highly resolved regional archaeological records - a captivating and fast-growing research situation! The very highest resolution records for the

4.2 ka BP megadrought include, prominently, the estimated 30-50% reduction in precipitation delivered by the Mediterranean westerlies in the eastern hemisphere, where they provide for dry-farming and irrigation agriculture across the Aegean, Levant, Anatolia, Mesopotamia, and Iran. Among these highest resolution archives are Mediterranean and Red Sea marine sediment cores, Italian, Albanian and Anatolian lake sediment cores (Weiss 2015), and recently published Greek and Iranian speleothem cores with sub-decadal sampling intervals.

Synchronous disruptions for the Indian Summer Monsoon are indicated at very high resolution at the Mawmluh Cave (Berkelhammer et al.2012; Kathjatyat et al 2018), with six-year sampling intervals, at paleolake Kotla Dahar (Dixit et al. 2013), and also now at Lake Rara in the Himalayas (Nakamura et al.2016), each presenting precipitation proxies for the Indian subcontinent and the monsoon's contribution of 80% of Nile River flow (Welc and Marks 2014). Further east, the trail of high-resolution aridification records extends to Inner Mongolia and to eastern China, where East Asian Summer Monsoon instabilities affected major Late Neolithic settlement systems (Donges et al 2015), and to Australia, where abrupt, dramatic and sustained weakening of the Indonesian-Australian Summer Monsoon is speleothem documented (Denniston et al2013). Also impressive are the high-resolution records in the western hemisphere, which include the ice core at Mt. Logan, Yukon (USA), with 10-year sampling intervals. Here, analysis indicates "major enhanced meridional flow coincident with major changes in the Pacific paleorecords of the balance between El Niño and La Niña, suggesting with other records that 4.2 ka BP inaugurated the 'modern' ENSO world" (Fisher 2008).

Similarly, the annual resolution of Great Basin tree rings indicates severe cooling with "no evidence that treelines have established at these altitudes since before the 2200 BC treeline drop" and "quite possibl[y] that high elevation ecosystems are now responding in a manner unprecedented in approximately 4,200 years" (Salzer et al. 2013). In sum, the high-resolution data now available indicate that this was a unique and global Holocene climate event second only to the 8.2 ka BP event in magnitude, but perhaps twice its duration. Hence, the onset of the 4.2 ka BP megadrought now marks the middle to late Holocene transition (Walker et al 2018).

How did societies adapt to what was a 200-300 year mid-Holocene megadrought? The proxy records for the interruption of the Mediterranean westerlies and the Indian Summer Monsoon are located where regional archaeological records are most numerous and highly resolved: the Mediterranean, the Levant, Egypt, Turkey, and Mesopotamia. Here, widely distributed and organizationally different, cereal-agriculture-based societies collapsed synchronously and coincident with the megadrought. The archaeological record for these societal collapses includes (1) intensive regional settlement surveys (2) high-resolution radiocarbon dating for abrupt abandonments in dry-farming domains across the scales of settlement, from villages to cities, and (3) epigraphic and radiocarbon data for the collapses of the region-wide, expanding Mesopotamian Akkadian Empire and the Nile-based Egyptian Old Kingdom (Ramsey et al. 2010; Weiss et al. 2012; Davis 2013). In these regions dependent upon rain-fed agriculture, the adaptive societal response linked with abandonment was habitat-tracking to riparian, paludal and karstic refugia.

Regionwide settlement surveys suggest that the populations abandoning the rain-fed plains of southwestern Turkey, western Syria and northern Mesopotamia became the habitat-tracking populations that settled along the banks of the Euphrates River and the karst-spring fed Orontes River. Similar habitat tracking occurred synchronously in the southern Levant and in the western Mediterranean.

Pastoralist adaptations

The Amorites, a large tribal confederation of pastoral nomad "campers", also exploited the Mesopotamian and Levantine landscapes, traversing the middle Euphrates River valley seasonally to steppe lands and dry-farming plains for sheep-flock forage. The abrupt desiccation disrupted this

ancient seasonal pattern, forcing the tribal groups to seek refugia along and down the Euphrates River. This infiltration of southern Mesopotamian urban kingdoms prompted their dynasts to construct the "Repeller of the Amorites" wall recorded in contemporary records. The wall proved porous, however, and within a few generations the former pastoralists' descendants became the Amorite rulers of Babylon. Indeed, the megadrought at 4.2-3.9 ka BP, serendipitously the best-documented period in cuneiform sources for southern Mesopotamia, was previously understood to represent inherently maximizing irrigation-based agriculture and hypertrophic city growth. But its anomalous character, a function of demographic and subsistence forces unleashed by the 4.2 ka BP megadrought, now encourages environmental historicization.

What caused the resettlement?

An explanation for the resettlement of Mesopotamian dry-farming domains, and the opportunistic sedentarization of formerly pastoralist Amorites at the abrupt ca. 1900 BC return of pre-aridification precipitation, now comprises a major anthropological and archaeological challenge, even though the historical moment is well-documented. The resettlement swiftly generated the famous warring kingdoms associated with the empire of Shamshi-Adad of Assyria and massive military struggles for rain-fed land and imperial power across west Asia.

Resettlement is apparently not self-evident: for instance, the post-megadrought abandonment of the central Maya Lowlands in the 9th century AD continued. Similarly, the variabilities within several other Holocene societal collapses are now available for cross-cultural exploration, including the 3.2 ka BP megadrought that caused Mediterranean and west Asian collapses and resettlements; the megadrought-induced 11th century AD collapse of the Tiwanaku state and its raised–field agriculture at Lake Titicaca in western Bolivia and subsequent highland-lowland habitat tracking; the synchronous Wari empire collapse in Peru that was followed by the Late Intermediate Period surge of warfare, elevated morbidity and excess mortality; the 13th century AD "Great Drought" and Ancestral Pueblo regional abandonments and habitat tracking to refugia in southwest North America; and the collapse and abandonment of the expansive "hydraulic city" at Angkor, Cambodia, following 13th-14th century AD decadal droughts and high-magnitude monsoons.

Erika Weiberg & Martin Finné

Contextualizing climate variability in Late Bronze Age Peloponnese (Greece)

Climate variability is a constant companion to human undertakings across time, perceivable as weather variations in the short-term and, perhaps, as climate change across time. The diversity of societal response as well as the numerous aspects of climate relevant for human societies make evident the need for contextualized approaches. As an effect of a focus on 'societies' rather than any smaller entity, however, studies of climate change and ancient societies are commonly conducted on a general rather than specific level. The emphasis on 'collapse' moreover, inevitably lead analyses towards the potentially negative impacts of climate change rather than more wholesale and inclusive evaluations of climate and ancient societies. Temporal and geographical scales are also important limiting factors, often favouring large-scale (such as 'East-Mediterranean') and/or long-term ('Holocene') perspectives, limiting the degree of detail that can be included in any one study. Such perspectives are crucial for initial chronological and geographical correlations between datasets and to pinpoint regions and times of special interest. In order to be more specific, however, and allow more of the details within each case study to come into play, we need to return to the local and the relatively more short-term.

The present chapter will take a closer look at the Late Bronze Age (LBA), also known as the Late Helladic (LH) period, on the Peloponnese peninsula. A recently published high-resolution climate record from Messenia (SW Peloponnese) provides a useful baseline for the whole peninsula (Finné et al., 2017). This climate record did not form continuously but the second growth period covers the period from

late Middle Bronze Age to the Early Iron Age (~1860–1000 BCE) and provide evidence of fluctuations between wet and dry climate conditions. The sequence starts with relatively wet conditions during the first 250 years (MH III–LH I) followed by dry conditions during the following 200 years (LH II) that end with a shift to wetter conditions around 1440 BCE (beginning of LH IIIA). The fourteenth century BCE (LH IIIB) constituted a transitional period marking the shift from wetter conditions to generally more arid conditions (LH IIIC–Early Iron Age). It seems clear that the two periods of prolonged wetter conditions may have enabled or enhanced the societal transformations and economic expansion noted for the periods, while the more arid conditions may have dampened expansion and also during certain circumstances increased the vulnerability of an economic system developed under more favourable climate conditions (Weiberg and Finné, 2018).

But what exactly causes vulnerability in a society, or the apparently variable sensitivity to climate fluctuations? How can we evaluate the levels of vulnerability to climate variability within the LBA societies? Recent vulnerability assessments of social-ecological systems include measurements of human and natural variables adding to the vulnerability load of societies, such as aspects of food and water supply, human well-being and connectedness (Kok et al., 2016; Nelson et al., 2016). Many of these variables are inextricably linked with climate and to contextualize climate variability, the pressure on these resources during variable societal and climatological regimes should be recognized and evaluated. The available information for prehistoric periods regarding these issues is naturally fragmented and quite varied. It is therefore desirable to establish as many parallel data series as possible, in order to add layers to the narrative and assess the evolution of interaction between them. In this chapter we select three variables that provide complementing layers to the narrative: 1) water availability; 2) food supply; and 3) connectivity, variables that address the exposure, sensitivity and adaptive capacity of LBA societies to climate variability (Adger, 2006).

Given the fragmented nature of the material, some of the data will need to be handled on a general 'societal level', but there is also room to consider regional differences within the Peloponnese. The two regions that stand out in terms of material availability is Messenia (SW Peloponnese) and the Argolid (NE Peloponnese). The location of these regions on each side of the mountain chain that transects the peninsula from north to south adds interesting dynamics to the narrative. Today, the annual precipitation in the regions of western Peloponnese is at least one third higher than in the eastern regions. While both regions housed palatial centres during the Mycenaean palatial period (LH IIIA–B, ca. 1400–1200 BCE), there are interesting differences in the societal setting, before, during and after this peak period of the Late Bronze Age histories of the regions (Galaty et al., 2014; Voutsaki, 1998). By contextualizing climate variability in LBA Peloponnese, then, we apply a holistic perspective on land use in order to assess both positive and negative effects of climate change and the shifting circumstances of life on different temporal and spatial levels.

Ann Brysbaert & Riia Timonen

Saving up for a rainy day? Climate events, human-induced processes, and their potential effects on people's coping strategies in the Late Bronze Age Mycenaean Argive Plain, Greece

This chapter investigates the resilience and risk management strategies of the Late Bronze Age (LBA) people against changing climatic conditions and other potential stress factors, such as monumental construction programmes, that led to the socio-political and economic crises which took place in the Eastern Mediterranean ca. 1200 BC.

Our case study area, the Argive Plain (northeastern Peloponnese, Greece), is renowned for accommodating many Mycenaean palatial centres (Mycenae, Tiryns and Midea) which were active in monumental construction programmes, craftsmanship and inter-Mediterranean trade during the Late Bronze Age (c.1600-1100/1070 BC). While this monumental architecture has been intensively studied,

the extent to which large-scale building programmes contributed to the socioeconomic and political changes and crises that took place in LBA Greece has not been investigated from a fully interdisciplinary perspective. We believe, though, that such a perspective fits squarely in a debate on 'climate and society studies'. Since agriculture and animal husbandry were predominant subsistence strategies for Mycenaean polities, intensive and prolonged building efforts requiring a consistent amount of human and material resources, may have affected local economies, and food provisions and intake profoundly. Drastic changes in the climate could have added extra pressure to maintain sufficient level of livelihood during the periods of intensive construction.

The relationship of climate change and the LBA Aegean 'collapse' has been a popular study arena for two decades. What such studies often lack are the consideration of the other potential factors that may have contributed in a crisis, and a question of the extent of the 'collapse'. First, both external reasons (climate changes with linked draughts, crop failure, diseases and changing birth/mortality rates; war; natural disasters; disruptions of inter-regional trade networks), but also internal ones (social unrest and war; human and natural resource exhaustion; overpopulation; overconsumption), have all been named but not been investigated by means of an inclusive methodology. Some scholars have also expressed the detrimental nature of mobilizing work forces in the Argolid to the sustainability of the socio-political structures toward c. 1200 BC. Second, our expanding knowledge about the succeeding periods after the LBA crises shows that the 'collapse' needs re-consideration (e.g. Middleton 2012). Reduced human activity in many crisis areas around the Mediterranean continued but past crises phenomena are in need of a very nuanced and contextualised approach (crucial work by Tainter). Importantly, creative adaptations to restraining factors must have affected several socioeconomic and political groups differently even in single contexts (e.g. Tainter 1988).

Interdisciplinary studies investigating the relationship of climate and ancient societies are increasing our knowledge of past climate changes, and, simultaneously, altering our views of people's responses to environmental crises. Ancient populations were not powerless in the face of rapidly changing climate, and awareness of their resilience and adaptive skills is increasing. There are emerging calls for investigating periods of stable climatic conditions instead (e.g. Caseldine & Turney 2010; Izdebski et al. 2016). Before the 'collapse', the Argive Plain societies had already shown remarkable resilience towards crises events (floods, earthquakes and fires), which could have threatened their economies. Therefore, in wider discussions on climate change and societal impact, it remains crucial to take the specific context into the equation since each (micro)region and its population will have had to be resilient to what came at them during their own lifetimes.

Against this background, we ask, firstly, what was the scale of a potential climate change that was powerful enough to affect people's adaptation and resilience to the extent that it threatened their economic subsistence strategies and that it also induced a societal crisis? This question is linked to the assumption that a drastic climate change could have caused major stress on the agricultural production, which in turn could have shaken the already unstable socio-political structures; the assumption itself begs investigation. Secondly, which strategies did people employ to prepare themselves for adverse conditions, such as climate changes and other factors that caused pressure on their daily-life subsistence? And thirdly, do we recognise other potential stress factors beyond climate-related ones which affected people's daily existence in the period before and after the c. 1200 'collapse'?

High-definition Eastern Mediterranean palaeoclimatic data are growing exponentially. Recent studies have illustrated a slow trend towards drier conditions in the BA Eastern Mediterranean (Finné et al. 2011; Moody 2005). People and the environment seem to have been well adapted to such long-term change. This can be witnessed in a steady population growth and intensification of agricultural production over the course of the Bronze Age in the Eastern Mediterranean area. Therefore, if a climate change acted as a trigger in the Bronze Age 'collapse', it is more likely that it was a short-term event into considerably drier or more humid conditions. Currently, high-definition paleoclimate data from the Argive Plain are unavailable. Despite the rapid development of scientific methods aiming at climatic reconstructions, we are yet unable to establish the scale of LBA climate fluctuations in precise terms such as rainfall or temperature changes. Additionally, we are only beginning to have the efficiency to place climate events within a chronological scale of decades. Therefore, even though unstable weather conditions, such as short pulses of extremely dry conditions, have been recognised, we cannot confirm that they occurred contemporary with the 'collapse' (Boyd 2015; Finné et al. 2014; 2017). While awaiting new data, we can, however, try to establish what could have been the extent (in years, rainfall, or temperature) of a climate event that could have drastically changed the socio-economic structures of a society whose subsistence was based on crop production and animal husbandry. In order to investigate the resilience and risk management tactics of the Argive Plain people against such climate change, the main subsistence strategies used in the Late Bronze Age have to be established. This can be achieved by combining existing data of archaeological (mortuary and settlement data), ethnoarchaeological and environmental studies (botanic, osteo-archaeological and zoological data). These data must be then contextualized in a much more complex network of the mentioned internal and external factors, particularly in the context of activities demanding large-scale and long-term efforts beyond their usual daily agrarian existence.

Methodologically, cross-craft interactions aid in describing how each of the internal and external factors were co-dependent and intersected with each other: producing tools to quarry, construct and garden; raising and maintaining oxen to plough and transport; building roads to access fields and tombs, and to transport goods; crop-growing for the family and to cater for construction labour and their draught animals. These cross-over actions impacted socially and technically on each other and their productions. Such a 'bottom-up' approach opens multi-dimensional models with unlimited contact nodes between people, crafts, their daily activities, and materials, and it dissolves the elite-labour dichotomy since nowhere were elite-sponsored monumental constructions or infrastructure possible without considerable levels of organized labour input, thus rendering all social groups co-dependent and on their daily provisions. Finally, through this methodology, we can begin to understand how a combination of several internal (e.g. monumental construction programmes) and external (climate change) components could have generated a growth of stress that perhaps culminated in a societal 'collapse'.

Anton Bonnier & Martin Finnier

Peloponnesian land-use patterns, settlement dynamics and climate variability in the first millennium BC

The aim of the current chapter is to examine the evidence for climate change as provided by three climate proxy records from the Peloponnese, recovered from speleothems collected in the Kapsia (Finné et al. 2014), Alepotrypa (Weiberg et al. 2016; Boyd 2015) and Mavri Trypa caves (Finné et al. 2017), and how such evidence can be linked to dynamics of settlement and land-use in Peloponnese

in the first millennium BC. From at least the late 8th and early 7th century BC we can track the development of significant settlements acting as central places in the Peloponnesian landscape, particularly in the northeastern part of the peninsula. Moving into the Archaic and Classical periods (ca. 700 BC to 323 BC), both written and material sources highlight the geopolitical significance of urban communities as autonomous or semi-autonomous communities (*poleis*) that would have been sustained by a surrounding territory (Hansen and Nielsen 2004). Agricultural production would primarily have been composed of dry farming dependent on sufficient precipitation to produce adequate yields to sustain growing populations. As proxy data demonstrate that shifts in climate and precipitation patterns occurred during this period we need to investigate whether such shifts impacted on the agricultural strategies of *polis*-communities.

Previous studies of ancient climate change and its impact on human communities have often utilized proxy data from records within the broader ambit of the Eastern Mediterranean (for Greco-Roman periods see for example Fuchs 2007; Bresson 2014). Such non-local proxy data is nevertheless problematic for a discussion on the potential impact of climate on human societies in the ancient Peloponnese (Finné 2014). In addition, a high degree of environmental fragmentation and various micro-climate types characterize the Peloponnese peninsula. Any investigation of the impact of climate change therefore needs to consider regional variability. The extraction of stable isotope data (oxygen and carbon) from speleothems provides new avenues through which we can investigate the potential impact of local climate variability and human responses within the Peloponnese (Weiberg et al. 2016). The climate information from the Peloponnese suggests wetter conditions during the Archaic period after a prolonged period of mainly drier conditions in the Early Iron Age. In the Classical and early Hellenistic periods climate conditions seem to have been even wetter. We can further observe a shift towards drier conditions in the late Hellenistic and early Roman periods, although the duration and timing of these dry intervals differ between the cave records. Within the current chapter we will therefore discuss how the evidence for climate change as derived from speleothem records can be compared and integrated with archaeological evidence for socio-economic dynamics and spatial changes in land-use strategies in the first millennium BC.

In terms of the archaeological record, site data from intensive field surveys have enhanced our understanding of land-use dynamics and allow us to track the presence and fluctuations of smaller rural sites in defined microregions, and are available from a broad east-west transect of the peninsula. Further site-based datasets are also provided by a number of non-intensive regional projects employing more extensive methodologies. In many of these datasets we can observe a take-off in rural settlements during the Late Geometric and Archaic periods, with maximum numbers being reached around Late Classical and Early Hellenistic times (in the late 4th and early 3rd century BC). In many of the eastern Peloponnesian datasets a contraction then occurs in the number of small rural sites in the Hellenistic and Roman periods (Bintliff 1997). But there are also a number of regional trajectories that need to be taken into account. In several of the western datasets we see maximum numbers being reached slightly later, in the Hellenistic period proper, with only a small amount of contraction taking place in the subsequent period of Roman rule (Stewart 2013).

On the face of it, the climate information provided by the stable isotope records compares quite well with the dynamics observed for the survey data and the pattern of rural settlement expansion and contraction. Increasing precipitation in the Classical period may for example have increased the availability of moisture in more marginal soils and may have prompted land-use

expansion and increased yields in the always drier northeastern Peloponnese. Similarly, the drier conditions in the later Hellenistic and Roman periods could potentially be connected with the contraction of rural settlements in the later Hellenistic and early Roman periods in the northeast.

Political agency has usually been highlighted as the primary cause behind these changes in settlement structures and land-use, supported by written sources that give us a comparatively good understanding of political dynamics and military activities, which will no doubt have impacted on regional settlement structures and land-use systems. The potential impact of environmental changes should not, however, be ignored, especially when considered as part of the broader matrix of underlying factors behind the restructuring of land-use systems. Building on models from more recent agricultural practice in Greece, inter-annual variability seem to have been calculated as part of agricultural strategies utilised by subsistence farmers in the Greek landscape, including buffering through overproduction in good years to compensate for the reduced yields in bad years (Halstead 1989; Forbes 2017). Ancient sources further demonstrate how trade and grain imports provided a significant security measure against droughts and food shortages in the short term. But in more prolonged sequences of climate change such security measures can become destabilised and difficult to uphold, particularly in terms of non-elite landowners and subsistence farmers.

In order to better compare palaeoclimatological records with site data derived from archaeological field surveys we nevertheless need to move beyond comparisons of site numbers per period and look more closely at spatial patterns of sites, the shifting nature of rural sites, and how these can be associated with changing land-use strategies. Through a review of legacy data derived from several survey projects we will provide a more nuanced interpretation of land-use dynamics in different areas of the Peloponnese from the Archaic and Roman period and how ancient climate change may be brought into this discussion.

J.G. Manning

Volcanoes, Nile variability and the course of Egyptian history. The historical and human dimension of climate change

This paper reports on ongoing work on the causes and consequences of Nile variability and societal responses. Its focus is on the interaction of environment, climate change and human society in Egypt during the last four centuries BCE. This was a pivotal, indeed transformational period in Mediterranean history that saw a major shift of Greek civilization to the eastern Mediterranean and, beginning about 200 BCE, the rise of Rome. Our work is driven by two main considerations. The first is that the documentation of environmental conditions from Ptolemaic period Egypt (305 - 30 BCE) is extraordinarily rich, among the richest for the pre-industrial world. The extensive economic and legal records from the period make it one of the earliest historic periods when material culture and written documentation combine to give us a clear picture of human-environment interactions. Secondly, Paleoclimatology has advanced dramatically in the last few years and is providing highly resolved temporal (sub-annual, annual and decadal time scales) and spatially specific data about patterns of drought and temperature changes. These very exciting developments means that we can, for the first time, combine climate and historical data on the same time scale. By exploring the many new techniques that integrate climate proxy with historical data to understand a new dimension of historical dynamics, the project will establish a new historical ontology for pre-industrial Egypt by describing, for the first time, a detailed example of a coupled natural-human system—how humans

have changed their environment, how human societies are impacted by environmental and climatic change and the two-way feedbacks between the two. This also has wider implications for the entire pre-industrial world.

Tyler V. Franconi

The Environmental Imperialism of the Roman Empire in northwestern Europe

The Roman Empire had a significant and sustained impact on the landscapes of northern Europe from the time of conquest to the end of the imperial period. A repeated process of deforestation and land clearance for agricultural exploitation led to a rapid onset of environmental change evident in a number of different archaeological, historical, and geomorphological datasets. This paper investigates how Rome caused environmental changes in the provinces of Germany and Britain and how these changes, in turn, affected patterns of settlement, economy, and frontier defence over the first five centuries AD.

Cynthia Bannon

Seasonal Drought on Roman Rivers: Transport v. Irrigation

Seasonal variation in the flow of rivers posed challenges for the Romans who relied on rivers for irrigation and transportation. While extreme floods have claimed attention of Roman writers and later scholars, the more persistent problem was low flow (Keenan-Jones 2013, 34-40), exacerbated by the warming climate of the late Republic and early Empire (McCormick et al 2012, 174-5). This chapter mobilizes Roman law to investigate Roman strategies for responding to low flow in rivers and to evaluate their success in this endeavor. I focus on the river interdicts because they illuminate the priorities and strategies that jurists, emperors, and individual litigants pursued when drought reduced river flow. Roman legal discussions document recurring tension between transportation and irrigation, two key factors in Rome's economic development (cf. Wilson 2015).

Early in the second century BCE the Romans introduced legal institutions to regulate the use of rivers, protecting first navigation and soon after, irrigation as well as fishing and watering animals. Roman law was a key component in the Roman response to environmental problems, and it allows us to bridge incomplete data on the environment and to probe the relationship between climate and

society. In this chapter, I first analyze these legal remedies and then I apply the lessons from the law to case studies built on literary, epigraphic, and archaeological evidence. In turn, the case studies offer new perspectives on the effectiveness and the limitations of Roman law for managing rivers so as to promote commerce and good governance. The analysis unfolds in four parts. The first section outlines the law on rivers, especially the praetorian interdicts. The case studies follow on rivers in Italy, Spain, and Greece.

The presentation focuses on the classical period of Roman law, c. 50 BCE–225 CE, which produced most of our legal writings and a critical mass of evidence for the case studies. The Romans addressed conflicts between irrigation and transport with praetorian interdicts. An interdict was a legal action granted by the praetor to protect an individual's interest in property, public or private. The praetorian remedies governed both river banks and the water itself. They include an early action protecting landowners from overzealous public contractors tasked with clearing river banks (Gel. 11.7.2) as well as five interdicts: four on public rivers and an additional one for activities requiring diversion of river water, especially irrigation (chapters 43.12, 43.13, 43.14, 43.15, 43.20 in the Digest

of Justinian). Public rivers were the first focus of these interdicts, signaling the state's interest in them an recognition of the public benefit, although most were later extended to cover private rivers. The public designation also matters because public rivers were defined as perennial or flowing year round (perenne, D. 43.12.1.1-3 Ulp. 68 ad Ed.). Perennial rivers could support both year-round transport and irrigation when it was needed in rainless summer months. Romans recognized this utility and attempted to harness it with legal institutions that negotiated these potentially incompatible activities: diversion of water for irrigation could diminish river flow so much that it hindered navigation. While such environmental problems were typically local (Maruotti 2009, 20) their impact could be empire wide when supplying Rome and its armies with grain or olive oil was at stake. Conflict over water could also destabilize local populations, creating risks for Roman officials on the ground and for the emperor. The legal sources show how the Romans conceptualized the problem and lend insight into imperial policy, as jurists participated in the rescript process and the emperors' consilium.

The case studies contextualize the conflict between transport and diversion in relation to economic development and imperial policy. Tiber floods motivated the Romans to build dams in the Tiber valley, which facilitated transport in the river's upper course (Pliny NH 3.53; cf. Aldrete 2007) with unintended consequences for agriculture in upstream communities (cf. Cic. Att. 4.15.5; Varro, Rust. 1.7.10). Literary sources show how the Roman regulation of rivers accommodated political, economic, religious concerns (esp. Tac. Ann. 1.79). The conflict between transport and irrigation emerges more clearly in the second case study on the Ebro and the Baetis, two rivers in Roman Spain, which are well documented by archaeological and epigraphic evidence. The land around both rivers was intensely farmed, producing oil and other crops (also mineral ore for the Baetis) that were shipped down river to supply both Rome and her armies (Campbell 2012, 250-62; Remesal Rodríguez 1998). These rivers illustrate the economic constraints that shaped the interdicts on rivers as well as the political role of Roman administration (lex rivi Hiberiensis, Hadrianic inscription recording by-laws of an irrigation community, FIRA (2012) 3.1.171-85; dedication to an imperial prefect who supervised transport on the Baetis, (CIL II.1180). The Greek East lends insight into the emperor's policy on rivers, including the negotiation of local and imperial priorities/interests and the trade-offs between engineering and legal solutions to conflicts over river use. Finally, the state's interest in the interdicts can be identified by comparison with imperial policy on hydraulic projects as articulated in Pliny's correspondence with Trajan about the construction of canals in Bithynia and the inscriptions recording Hadrian's interventions at Lake Kopais in Greece (Boatwright 2000; Knauss 1995; Froriep 1986). Together the case studies show that the river interdicts addressed real issues that affected economic activity and governance across the empire. Even if the legal evidence cannot be connected with identifiable people and place, it offers significant information about the response to the impact of climate on their world.

Brandon McDonald

The Antonine Crisis: Climate change as a trigger for epidemiological and economic turmoil

For my chapter, I shall focus on the period of climatic variability happening in the mid-to-late second century AD, its connection to the Antonine Plague (AD 165-190), and the societal downturn that followed. My paper will show that there is a link between second century AD climate cooling and the Antonine Plague, demonstrating that climate change was a leading catalyst for the spread of this epidemic. Simultaneously, the Roman Empire experienced significant economic and demographic loss

induced by the period of climatic variability mentioned. I intend to disentangle loss caused by agricultural decline from loss caused by plague, while highlighting climate change as their common denominator.

Scientific research has shown that two volcanic eruptions—one in AD 163/164 and another in AD 171—spurred a cool period that directly correlates with the rise and spread of the Antonine Plague, probably the variola virus, better known as smallpox (Büntgen et al. 2011, 578-582; Büntgen et al. 2016, 231-236; Sigl et al. 2015, 543-549). Most recently, I have conducted research exploring whether there is a link between a cool climate and the prevalence of smallpox (McDonald, forthcoming 2019). I found that lab testing and epidemiological studies conducted before the eradication of smallpox show the virus both reacts and persists better in cooler temperatures (Huq, F. 1976, 710-12; MacCallum and McDonald 1957, 247-254; Nizamuddin and Dumbell 1961, 68-9; Nishiura and Tomoko, 1-10).

This makes it a priori probable that the drop in temperature preceding and lasting throughout the Antonine Plague was not merely coincidental, but causal. In addition to explaining the causal link between a cooler climate and smallpox, I will discuss the origin of the disease, both in general and in relation to when it first struck the Roman Empire. By examining the phylogenetic evidence, I will clarify why it is the strain of disease responsible for the Antonine Plague originated in either central Asia or Africa (Babkin and Bakina 2015, 1100-12; Li, Y. et al. 2007, 15787-92; McLysaght, A. et al. 2003, 15655-60; Harper 2017, 91-94; Zelener 2012, 167-177). More importantly, I will show that the plague probably first reached the Roman Empire from Asia, and that second century AD-climate change happening in central Asia was its main trigger.

In the second part of my paper, I will use archaeological, literary, and scientific evidence to show that the Antonine Plague caused major demographic and economic losses for the Roman Empire, most recently shown in a study led by Joe McConnell in 2018. The evidence shows that these losses were not restricted to only a few parts of the Empire. Nevertheless, the literary evidence suggests certain parts were affected far more than others; for example, Italy and Asia Minor appear to have experienced more damage than Roman Egypt (Elliot 2016, 10-11). This is problematic, as scholars tend to use decline in second century AD-Roman Egypt as a proxy for plague-impact throughout the Empire (Duncan-Jones 1996; Scheidel 2002; Bagnall 2002; Harris 2012, 334). The goal for this section is to determine which parts of the Empire were actually affected by the plague, and to distinguish whether those areas suffered mainly because of the plague, or because of factors such as agricultural decline caused by an unstable second century AD-climate.

In conclusion, my paper will highlight the role of climate change as the origin for the epidemiological and economic crises in the latter half of the second century AD. With this focus, I aim to differentiate the widespread conflation of economic loss caused by a changing landscape from loss caused by disease, thus offering a more accurate survey of the causes for, and types of, distress experienced during that period.

Paul Erdkamp

Climate change and the productive landscape in the Mediterranean in the Roman period

During the past decade, several studies have related the rise of the Roman Empire – in terms of economic prosperity, population, political stability and military power – to the Roman Climatic Optimum, and its subsequent decline to the so-called Late Antique Little Ice Age. Adverse climate change is generally thought to have disrupted the food supply, leading in turn to misery and increased

mortality, and to social and political unrest. Climate change is often claimed to have had an even more fundamental impact on human society: warm periods increased the carrying capacity of the land and thus allowed populations to grow and prosper, while cold periods exactly did the opposite. However, a thorough analysis of the causal links between climate change and agricultural productivity on the one hand, and agricultural productivity and the food supply on the other, is often missing.

It will be argued that there is no good reason to assume that the Roman Empire had reached the ceiling of sustainability. The impact of changes in temperature and precipitation are much more diverse and complex than more or less intuitively assumed in some of the recent studies. Cereals and pulses were the staple foods of the Roman world and the fluctuations in temperature remained well within the range of growing conditions of the main crops. The intuitive link between adverse climate change and famine is generally based on instances of extreme weather and on the experiences of peoples who lived on the margins of the biological requirements of arable crops, such as the extreme north or semi-arid regions. If we want to test the hypotheses regarding the demographic, economic and political consequences of climate change in less clear-cut cases, we should go beyond intuitive conjectures and analyze the consequences of climate change for agriculture more thoroughly.

This brings us to the second element: the concept of 'carrying capacity'. It is often claimed that warm periods increased the carrying capacity of the land and thus allowed populations to grow and prosper, while cold periods exactly did the opposite. The balance between land and population brings us back to Malthusian pressure, with the added element that climate change means that not only population is a varying factor, but that also the carrying capacity of the land varies independently of human action. However, the argument is based on the wrong assumption that population levels are determined by an environmentally determined carrying capacity of the land. In reality, agricultural production is not only determined by such ecological factors as soil, yields and weather, but also by such societal factors as the structure of landholding, the extent of (under)employment, of specialization and of market integration. In other words, it is an oversimplification to argue that climate change lowered the carrying capacity of the Roman world, causing a breakdown of the political institutions and economic structures of the Roman state.

Paul Kelly

Risks for farming families in the Roman Empire

This chapter seeks to model the impact of how climate would have impacted farmers in the ancient world. It will deal with how the results of climate science research could be used to improve our understanding of ancient society, and in particular, that of the Roman Empire. Climate naturally had a direct and important impact on this essentially agrarian economy – but can we quantify its relative importance compared to other risks?

An econometric model which outlines the risks and returns from land ownership and tenancy will be presented. This model takes a 'bottom up' microeconomic approach by simulating, in a stochastic way, the financial and family outcomes for different types of young couples: petty landlords, smallholders and tenants. It follows these families over a generation to see who prospered, fell into debt or were ultimately ruined. Simulation of large landowners and villa or slave-based production models lie outside the scope of this chapter. The time period chosen is the high empire around the end of the first century AD which was a period of relative price and political stability. Two geographic locations at opposite ends of the Empire are modelled: Egypt and North-Western Europe. These two locations had very different climates and social environments but were both within the institutional

framework of the Empire. Our knowledge of the details of these environments is much greater for Egypt than for North-Western Europe, given the wealth of evidence from documentary papyri, but in both regions a range of bio-archaeological data is available to assist in setting the parameters of the model.

The model assumes that the land concerned is sown primarily in wheat and was farmed by a family unit. The area that the tenant farmed was a plot whose yield was sufficient, in years when there was a good harvest, to provide a standard of living for a young family which was somewhat above subsistence level. The smallholder is assumed to own and farm a plot of the same size. The petty landlord is assumed to own two plots of this size, one which was farmed by their own family and the other leased out to a tenant. Certain fixed parameters such as the necessary calorific input for adults and children are assumed. However, many of the critical input variables for the model are strongly climate dependent and should be informed and guided by the available evidence from climate and crop science. Key climate-dependent assumptions relate to the total expected harvest yield, the variability of this yield, resultant cereal prices, spoilage rates for stored cereals, and, for Egypt, the risk of Nile flood failure.

However, climate was not the only significant risk faced by farming families. Family size had a substantial impact on the likelihood of prosperity or ruin as did the level of discretionary spending by the family above that required for subsistence. The relative importance of these risks compared to climate risks is assessed and the resulting economic rational for the abandonment of newborns examined. The role of Roman institutions in aggravating or mitigating farming risks is also modelled. For instance, high land taxation would increase risks that families faced whilst effective state granaries or efficient credit structures would mitigate risks by helping tide families over bad years.

The results of the models will be presented in probability distributions. The expected probability of ruin or falling into debt for each category of farmer will also be given, as will the expected increase in wealth over a generation for those who prospered. The information thus provided will reveal insights into social mobility or immobility between different classes and the propensity for land ownership to concentrate and increase inequality over the longue-durée.

Annalisa Marzano

Figures in an imperial landscape. Ecological and societal factors on settlement pattern and agriculture in Roman Italy

The geographical areas of Cisalpine Gaul and Etruria were objects of important long-term field survey projects and excavations that have produced a wealth of archaeological data. This chapter will investigate trends in settlements patterns and urban occupation in these regions for the period spanning from the 2nd to the 5th centuries AD. The 3rd century AD was a period of great political and economic instability in the Roman Empire. In Italy, starting with the second half of the 2nd century AD, archaeologists have registered signs of 'decline' and 'crisis', at both rural and urban sites: the quality of repairs observed in building diminishes; fewer major public building projects are undertaken; at villas sites, previously luxurious residential rooms are instead used for small production actives or to house burials, while some rural sites appear to have been abandoned altogether. Some scholars have taken this evidence as an indication that Italian agriculture, particularly viticulture, was in crisis; others have identified the cause in the demographic consequences of the Antonine Plague and in the 3rd-century political instability. Recent studies, however, have stressed the diverse rural settlement trends that one can observe across the peninsula. Work on imperial property has also highlighted the socio-

economic impact imperial ownership had on the creation and maintenance of regional infrastructure. Conversely, when emperors ceased to regularly visit these properties, both urban living and management of rural resources seem to have broken down. Climate change has recently entered into the picture and scholars have been asking, for instance, whether the growth, in late antiquity, of marshlands in certain areas was due to the end of the Roman Climate Optimum, followed by colder average temperatures and inconstant precipitation. Some evidence seems to point to climate change, as in the case of Mutina (mod. Modena) in the 3rd-6th centuries AD: recently, the devastating flood events identified and the spread of wetlands have been connected with seasonal variability and inconstant precipitation (Bosi et al. 2018). At other times, palaeoenvironmental studies rather point to soil erosion due to reduced maintenance of farmland and deforestation, in other words to anthropic causes and the breakdown of societal organization (Amato et al. 2012).

The aim of the chapter is to assess whether the decline in rural (and urban) settlements that can be observed in parts of Italy from the 3rd century onwards was a result of post-Antonine plague demographic collapse, climate change, or the outcome of other processes, such as the transformation of Italy into a province and changes in landholding patterns and crop management. The case studies discussed in this chapter will stress the high degree of regional differentiation and complexity that can be reconstructed for Roman imperial Italy on the basis of archaeological data. While it is not easy to identify the cause of the empirical phenomena that one can infer from the archaeological record, the data from the two case studies presented do suggest that social and economic explanations reflecting different regional realities are in most cases the most plausible explanation of the phenomena discernible in the archaeological record.

Dimitri Van Limbergen & Wim De Clercq

Viticulture as a climate proxy for the Roman world: evidence and problems

Vine growing is highly sensitive to climate. Viticulture possibilities are especially linked to growing season temperatures, in particular for the period between April and August (late spring to mid-summer). Temperatures are a major factor in determining the boundaries of regions suitable for viticulture, and significantly impact grapevine phenology throughout the full cycle of development. In turn, wine grape phenology is intrinsically linked to the timing of grape maturation, and thus to the date of the grape harvest. So basically, higher temperatures allow for the expansion of vineyards towards higher elevations and into more northern areas, and accelerate fruit maturation and advance grape harvest dates (GHD). Colder temperatures have the opposite effect. This means that the geographical location of vineyards and annual grape harvest records can be proxies for temperature variations. Herein lies the link between viticulture and past climate reconstruction.

In this chapter, we examine the potential of viticulture as a proxy for climate reconstruction in the Roman world. Several studies have successfully used historical grape harvest time series for studying climate evolution in Medieval and Early Modern Western Europe. Unfortunately, such precise and secure documentary data are unavailable for the Roman era, for which all textual information on viticulture is narrative or descriptive in nature, containing at most some numeral titbits. This is a serious obstacle. Nevertheless, we argue that systematically bringing together all documentary evidence with potential climatic value can still be of importance for detecting climatic variations on wider temporal and/or spatial scales within the Roman world.

To this purpose, we will look at three types of datasets: archaeological data (vineyard traces and press remains at higher altitudes, or in areas outside the direct sphere of the Mediterranean climate region; that is, specifically in the more northern areas of the Western Roman Empire; e.g. archaeology now unequivocally shows that viticulture was very well possible in southern Britain from the 2nd century AD onwards); textual sources (in particular the manuals by the ancient agronomists, but also written calendars and legal texts; in the latter case, annual Nile flood records can be of special importance, as they coincided with the period of the grape harvest in Egypt); and iconography (rustic calendars or seasonal representations on mosaics, frescoes and stone reliefs; especially with regard to the months of August, September and October). In our examination of these datasets, we focus on three types of information that may be interpreted climatically: mainly vineyard/press location (1) and grape harvest periods (2), but also wine quality (3), as the latter can be affected by temperatures in the months preceding the harvest (mostly influencing the sugar/acidity balance in the grapes).

Our discussion focuses on the critical evaluation of the assembled datasets as climatic proxies for the Roman world, taking into account their strengths and weaknesses (e.g. representative value and their possible dependence on other factors than climate, such as cultivation techniques, the use of certain grape varieties, the types of wines that were commonly produced, or other socio-cultural practices). As such, we intend to evaluate to which extent – if any at all – these datasets hold promise for informing future climatic reconstructions.

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The social metabolism of past societies. A new approach to environmental changes and societal responses in the territory of Sagalassos (SW Turkey)

All human societies, past and present, are intrinsically embedded in their natural environment. From this environment, necessary energy (in the form of foodstuffs) and resources such as wood, minerals, and metals, need to be derived to sustain people, communities, and settlements. Yet, too often this relationship has been portrayed as static and unidirectional, with little regard for the two-way feedback loops between society and nature. In this sense, the landscape is depicted as little more than a static background decor for the 'play of life' to unfold. Archaeologists have by now increasingly come to realize the importance of understanding the intricate two-way interconnections between society and nature. The effects of climate changes - such as rising and falling temperatures or precipitation levels - are also increasingly recognised and considered essential parameters to be taken into account if we are to truly understand the full scope and impact of societal changes and developments that we observe in the archaeological record.

Archaeologists have long focused on the concept of "carrying capacity" to try and elucidate both the potential and limitations of the environment for societal development. The term was first used at the end of the 19th century in ecology and has since come to be understood as 'the maximum population of a given organism that a particular environment can sustain'. It has contributed greatly to our understanding of the relationship between population growth - both human and animal populations - and resource availability. However, the framework has serious shortcomings. First and foremost, it is a static concept, relying on conceptualisations of biophysical and social dynamics as tending towards stable equilibrium states and treating environmental change as exceptional 'noise'

that is to be analytically suppressed. The concept thus deals poorly with changing environmental circumstances and societal needs through time.

Instead, archaeologists and environmental scientists alike have in recent decades increasingly started to turn to concepts of resilience and sustainability to frame human-environment interactions. In such approaches it is considered that, on the one hand, the availability of energetic potential is dependent on the nature and properties of this environment - including climate, topography, soil composition, and vegetation - whereas, on the other hand, the efficiency of its exploitation is dependent on the technological and organizational level of a given society. Both spheres mutually influence, intensify or neutralize each other. To effectively study the flows of energy and resources between society and nature, both systems need to be fully taken into account. Much recent work on human-environment interactions builds on the framework of social-ecological systems (SES) as intrinsically coupled spheres subjected to such recurrent, mutually influencing feedback loops.

One approach within the overall SES framework which may offer great potential for archaeologists in dealing with the dynamic nature of human-environment interactions is that of "social metabolism". Broadly defined, this concept encompasses the entirety of biophysical analysis of exchanges in matter and energy between society and nature. Three types of material and energy flows - input flows, inner flows, and output flows - within the system can be distinguished, passing through five metabolic functions: appropriation, circulation, transformation, consumption and excretion. To successfully apply such a framework for societies in the past, we need to move beyond solely archaeological perspectives, by opening up disciplinary boundaries to work within an interdisciplinary research framework. The importance of such interdisciplinary collaborations is these days widely recognised and is being backed-up by increasingly impressive research results.

This paper wishes to contribute to this ongoing trend. The authors are part of a recently established interdisciplinary research consortium (called SuRP+: Sustainability and Resilience in Past & Present Populations) aiming to bring together young scholars from a wide range of disciplines (archaeology, geography, demography and environmental sciences) to work on sustainability and resilience in the past and present. In this paper, we wish to use our combined expertise to elucidate patterns of environmental circumstances, climatic changes and societal responses. We will work with extensive archaeological and environmental datasets generated by the Sagalassos Archaeological Research Project. The Sagalassos project has been conducting interdisciplinary research at the archaeological site of Sagalassos and the surrounding territory (located in southwest Turkey) for over three decades, providing a unique context for the type of research proposed here.

We will compare two case studies of environmental and societal dynamics and changes on a local and regional scale. Both cases represent different time periods characterised by marked phases of climate changes, which allows us to trace different scenarios of societal responses. The first case is associated with the so-called Beyşehir Occupation phase (BOP) characterised by warmer and more humid circumstances, generally dated from 3500 to 1300 BP. The occurrence of the BOP has been identified throughout many parts of the Eastern Mediterranean - including Anatolia and the Aegean world - and is also indicated in all records from the territory of Sagalassos, with the timing of the onset of the phase differing between locations, ranging from c. the 8th to 3rd centuries BCE, covering the Iron Age to Middle Hellenistic period. This phase favoured the spread and intensification of agricultural and arboriculture production and is often associated with the first attestations of anthropogenic cultivators. The second case focuses on the Middle Byzantine (11th-13th c. AD) period, which is

characterized by the Medieval Climatic Anomaly (MCA), which, in contrast to the BOP, expressed itself in colder and wetter climatic conditions. A gradual change towards a cooler, yet dryer climate, already started off from c. 450-650 AD. These conditions were less favourable for crop cultivation and arboriculture, but stimulated a shift towards pastoralism.

Both periods are thus marked by changing environmental conditions that required society to alter their subsistence strategies, economic system and social organisation, offering highly suitable case studies. Several topics will be explored further within the framework of metabolic flows of energy and resources characterising human-environment interactions in these different periods, including resource exploitation, agricultural production, human labour, population growth, life cycle impacts, vegetation diversity and composition, economic production and exchange, territorial development, and socio-political organisation. By comparing different instances of climatic shifts and associated societal responses within these topics, a better understanding can be gained of the mechanisms behind the observed changes. A major goal would be for example to disentangle in which instances observed environmental changes are mainly human or climate induced, or a mixture of both. This way, the authors wish to contribute to the advancement of research in human-environment interactions in archaeology and related disciplines, one of the major goals of SuRP+.

Paolo Maranzana

Resilience and adaptation at the end of Antiquity: an evaluation of the impact of climate change in Late Roman Central Anatolia

This paper considers the impact of climate on the processes that led to the end of Antiquity (4th- 7th centuries CE) in Anatolia (Turkey), the only region where the radically transformed Late Roman/Byzantine administrative institutions survived into the Middle Ages. The specific focus is the Central Anatolian Plateau, a landlocked, semi-arid area located mostly above 1000 m a.s.l.; here, changes in climate and availability of water can have an especially severe impact on the development of agriculture. This region of Anatolia has also been traditionally considered the least populated and agriculturally productive in the Roman period, but it became, nonetheless, the heartland of the Empire after the 7th c. CE. It, therefore, offers an excellent case study to evaluate the resilience and adaption of local communities in the face of climate and socio-economic change in this transitional period.

Recent environmental studies, based on cores collected in 20 lake sites, demonstrate that climate change only moderately affected agricultural output and land exploitation between the 4th and 7th centuries CE. According to the data collected, both coastal and inland Anatolia experienced a dry and warm environment from the 4th until the beginning of the 6th c. CE (ca. 530s CE), when the climate became wetter and cooler until ca. 660 CE. In the late 7th c. CE, temperature seems to have risen slightly while remaining wet until ca. 750 CE, when the environment turned drier again. Palynological evidence indicates that the dry and warm period (up to the early 6th c. CE) accompanied a phase of agricultural expansion where cereals and tree crops (olive, walnut, vine, manna ash, chestnut) were progressively more intensively grown. This agricultural uptick, observed both on the Anatolian coasts and on the central high plateau, is also confirmed by the increase in land occupation detected through archaeological field survey; the best evidence for Central Anatolia comes from the Konya Province (ca. 1200 m a.s.l.), situated about 250 km south of Ankara. Archaeological investigations have detected an increase of ca. 20% in the number of rural sites as well as a similar

overall growth in the amount of occupied land. In particular, many of these new sites were often located in marginal areas, which were hardly exploited before the late 4th and early 5th centuries CE.

The wetter and cooler period (ca. 530-660 CE) does not seem to have affected significantly the development of agriculture in Central Anatolia, as productivity and rural occupation continued during this period. Conversely, in coastal areas, the later 6th c. CE marked a time of decrease in production of tree crops and cereals; by the mid-7th c. CE, the central plateau had become the most stable and productive area in Anatolia. Climatic analysis showed that a significant drop in production in Central Anatolia occurred only in the later-7th c. CE; this is clearly unrelated to any "worsening" of climatic conditions in Anatolia, which remained consistent until the first half of the 8th c. CE (ca. 730 CE). Thus, the reasons behind fluctuations in agricultural production must be found elsewhere and cannot be directly associated to changes in climate.

Further explanations for the decrease in agricultural output in the late 7th c. CE can be offered by the analysis of production and distribution of manufactured goods, such as ceramics, which often circulated alongside crops. Recent research on Late Roman ceramics has underlined an increase in commercial connectivity between different areas of the Roman East during the 4th and 5th centuries CE, where transportation vessels (amphorae) and table ware (red slip fine ware) were traded extensively across the Eastern Mediterranean. For the case of Anatolia, two main events increased the economic integration of its regions: 1) the foundation of Constantinople (324 CE) and 2) the reorganization of the annona (state-line of supply for army and capital city), after the Vandals took over North Africa in the 440s CE. Recent investigations show that these reforms made the state-supply progressively more reliant on goods produced in Anatolia and the rest of the Roman East, and, thus, stimulated trans-maritime trade relations. The later 6th and early 7th centuries CE, by contrast, marked the unraveling of this system, which affected negatively those Anatolian regions (Cilicia, Pontus, and Bithynia, for example) heavily reliant long-distance trade. The fluctuation in economic integration of coastal areas seems to be consistent with changes in the agricultural output, which grew in the 4th and 5th centuries CE and decreased in the 6th c. CE.

When we turn to Central Anatolia, increase in agricultural productivity was not related to long-distance trade; on the contrary, the region underwent a time of progressive economic isolation between the 4th – 7th centuries CE. This is well expressed in the production and circulation of Red Slip table ware (LRFW), which was entirely produced and distributed regionally, in marked contrast with what observed in the coastal areas of Anatolia, where imports were very common. The economic independence of Central Anatolia, thus, shielded this region from the fluctuations of the coastal markets, reliant as they were on long distance trade and the state demand. Since the growth in agricultural output in Central Anatolia was based on local markets, the region maintained its higher productivity until the later 7th c. CE, when the Arab invasions (among other factors) caused a major disruption in the socio-economic and demographic makeup of the region.

To conclude, it is therefore clear that Central Anatolian rural communities adapted to climate change, which hardly impacted the level of agricultural productivity, while the reliance on local markets made them resilient to the fluctuation of long distance trade. It was only when the Arab incursions broke down this equilibrium, the productivity of these communities declined.

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Late Antiquity hydrological changes: spatio-temporal characteristics and socio-economic impacts in the Central and Eastern Mediterranean

Late Antiquity was a period of large-scale climate fluctuations and abrupt climatic shifts in the Central and Eastern Mediterranean. Between 300 and 700 AD, the central and eastern parts of the Mediterranean saw a sequence of dry and wet decadal to multi-decadal intervals, as well as annual to multi-annual droughts (e.g., Decker 2017; Izdebski et al., 2016, Labuhn et al., 2018; McCormick et al., 2012).

The exact spatial and temporal pattern of these hydrological changes, however, remain poorly documented due to current limitations of climate proxy records such as tree rings, lake and marine sediments and stalagmites. There are large spatial gaps and records are often seasonally biased (e.g., tree rings), coarsely resolved (e.g., lake and marine sediment sequences) or suffer from considerable chronological uncertainties of several decades. Furthermore, the interpretation of climate and environmental proxies such as oxygen isotopes remains ambiguous. This is also often true for archaeological records and to a lesser extent to historical evidences. These uncertainties should thus be taken into consideration for the assessment of the potential socio-economic impacts of climatic changes in the Central and Eastern Mediterranean in Late Antiquity.

In the fourth and fifth century, palaeoclimate records show a longer dry period that extended from northwest Italy to the Black Sea and the southeast corner of the Mediterranean Basin. The onset of this "Late Roman Drought" seems to have occurred progressively from the east to the west, and proxies record varying lengths across each region (see also Izdebski et al., 2016; Labuhn et al. 2018). Interestingly, except for local weather-related subsistence crises (Harper 2017; Izdebski et al. 2016), there is no clear evidence that this dry period had any major socio-economic consequences.

A number of proxies show that the dry phase ended rather abrupt in the course of the fifth and sixth century and was followed by more humid conditions, the period which we label here as the "Late Antique Pluvial". Proxy records from the Nar and Van lakes show wetter conditions in the sixth and the seventh century, respectively (Dean et al., 2015; Jones et al., 2006; Wick et al., 2003). Wetter conditions during the seventh century reveal records from the Sofular Cave in the Black Sea area (Göktürk et al., 2011). The humid period is synchronous with what seems to be the climax of rural prosperity in the Eastern Roman Empire (Decker 2017; Izdebski 2013). While the dating of the majority of the archaeological survey projects carried out in this region does not allow for precise correlating of the agrarian and climatic developments, in some cases they indicate that in the late fifth into the sixth century regions as the Golan and the Negev reached their highest density of settlement (Cameron 1993). After the fifth century began the drop in the Dead Sea level and the longest hiatus in the chronology (Bookman et al., 2004).

The abrupt dry-wet transition in the central-eastern Mediterranean and the prolonged humid period of the fifth to the sixth and in some regions to the seventh century appear to concur with the cold Late Antique Little Ice Age (LALIA) identified over entire Eurasia (Büntgen et al., 2016; Luterbacher et al., 2016). LALIA was likely a response to a number of strong tropical volcanic eruptions, a decrease of solar irradiance and associated dynamic interactions between the Atlantic, the sea ice conditions and the continental climate. Preliminary paleoclimate modelling results also show that Eurasia and the Mediterranean experienced colder and wetter winter conditions compared to the fifth and seventh centuries.

In our paper, we will revisit the previous discussions of the Late Roman Drought and the Late Antique Pluvial by combining palaeoclimate proxy records, with palaeoclimate model simulations,

which allow for a more precise definition of the spatial and temporal scope, and the actual external and internal forcing of the phenomena observed in the proxies across the Mediterranean. The processes and underlying dynamics during the dry/wet phases and the abrupt dry-wet transition in the central-eastern Mediterranean are unclear to date and will be studied with additional proxy evidence and climate model/data comparisons. For the model/data comparison we will use simulations that were carried out with MPI-ESM-P following the PMIP3 protocol for last millennium simulations (Braconnot et al., 2012; Schmidt et al., 2011), but have been extended to cover the entire Common Era. In addition, new MPI-ESM-LR transient simulations will be included applying the CMIP6/PMIP4 protocol for the "past2k" experiment (Jungclaus et al. 2017). Based on our results, we will also offer a more detailed discussion of the socio-economic impacts of both climatic phenomena.

Peregrine Horden

Climate, resilience and disease in the post-Roman north west

The point of departure of this paper will be the highly divergent views of the 'plague of Justinian' and its effects – based on the latest aDNA findings from Spain and Bavaria and highly divergent readings of their significance, minimalist and maximalist. Treading a cautious path through the scholarly minefield, I shall incline toward minimalism by looking especially at what are probably the least studied areas in the historiography of the 'early medieval pandemic' (as I more neutrally call it), that is, England and Frankish Gaul, from the sixth to eighth centuries. I shall mention the best documented descriptions of and responses to plague, but try to broaden the discussion out both to signs of socio-economic collapse (or the lack of such signs, the resilience), and to other diseases, e.g. malaria, asking how far the whole ensemble, the 'pathocoenosis', can be related to climatic fluctuations.

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