

THE MEDITERRANEAN ENVIRONMENT IN ANCIENT HISTORY: PERSPECTIVES AND PROSPECTS*

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The papers at the conference from which this volume is derived concentrated chiefly on energy, climate and climate change, and environmental questions of land use, deforestation, mountains and rivers. This reflects perhaps the current focus of historical research on the ancient environment—but we should recall that several important facets of the environment, including the marine environment, pollution, and natural disasters such as earthquakes and volcanic eruptions (on which more below) are absent from such treatments. Overall, they reflect not only a current interest in mankind's impact on the natural environment, but also renewed interest, in the face of advances in climate science, in how the environment influences human action, and history.¹

ENERGY

Paolo Malanima's chapter stresses the importance of understanding the 'energy budget' when considering ancient economies. His questions are important and go to the heart of debates over the environment and ancient economic performance. Although he presents no real data for the ancient world, his model suggests some of the constraints on pre-industrial societies and explains why climate change would have had such a big impact on the Roman world and other pre-industrial societies. But the approach remains very general, with sweeping assumptions and questionable proxies. The graph of femur length in fig. 3 shows a rise initially because most British samples were excluded from the period AD 1–49 as Britain lay outside the Roman Empire for most of this period, but were included in the AD 50–99

* I am very grateful to William Harris for inviting me to be a respondent at the conference in Rome, and to all the participants for stimulating debate and ideas. I thank especially Sturt Manning, Mike McCormick and Kyle Harper for helpful discussion and references.

¹ This is not to be confused with environmental determinism, which is the notion that the physical environment determines human character and intelligence.

and later periods; the rise is partly thus due to the inclusion of more northern European samples from populations with a high degree of pastoralism and thus milk and meat consumption, which typically correlate with greater stature. Archaeological wood remains cannot straightforwardly be used to estimate the extent of forest clearance, *contra* his fig. 6. Moreover, the discussion ignores cultural specifics, which for the Roman world in particular, would include the need for fuel generated by the widespread practice of public bathing in large, heated bathhouses. Nor can we safely assume that 'fuels different from firewood represented a negligible share of the total': archaeological evidence from North Africa, Syria and Italy shows that olive pressing waste was used to fire kilns and even bakers' ovens at various sites, some but not all of which lay in wood-scarce regions.² There is a methodological danger in borrowing figures (for fuel consumption per capita) from other periods or places and then using these to establish Roman performance or consumption or whatever—it denies us the possibility of finding out what was specific to or characteristic of the Roman world, which is precisely what we want to know. For example, the assumption that sailing ships were not more numerous in the Roman Empire than in medieval and early modern Europe is not self-evidently secure, nor were ships of 400 tons 'rare'; there were clearly fewer of them than 100-ton ships, but that is not the same thing. Nor is it quite the case that water-mills and sailing ships between them provided 100% of the mechanical energy supplied by non-biological converters. Besides grain mills, water-power was also used to drive saws and ore-crushing devices, and also water-lifting wheels for irrigation. A consideration of the energy budget ought also to include the use of flowing water for downstream river transport, which led to significant differences between the costs of upstream and downstream transport.³ The potential for downstream river transport was of course regionally limited, but had a substantial effect on shaping regional economies of major river valleys, especially the Nile (100-ton barges were not uncommon), the Rhône and the Rhine.⁴ As to the role of animals in the ancient economy, we should remember that they were not used only for ploughing and transport, but for driving irrigation machines, at least from the third century BC onwards.⁵ There is clearly

² Wilson 2012b, 149–150. Kilns at Leptiminus (Lamta, Tunisia): Smith 2001, 434–435; kiln at Androna (al-Andarin, Syria): Mango 2011, 108; bakeries at Pompeii: Monteix 2009, 7–8. Cf. McCormick 2012, 73.

³ Russell 2009, 113–114.

⁴ Cf. Franconi 2013.

⁵ Oleson 1984; 2000; Wilson 2012b; Malouta and Wilson 2013.

much more to be done in teasing out the similarities and differences in the availability and use of the energy budget in different pre-industrial societies, Rome included.⁶

CLIMATE RECONSTRUCTIONS

An important study in *Science* published in February 2011 presented a climate reconstruction for central Europe over the last 2,400 years, based on northern European tree-rings, including April–May–June precipitation levels and June–July–August averaged temperatures normalised to the twentieth-century averages.⁷ The study noted some suggestive parallels with major historical events: the period of Roman conquest coincided with a marked dip in summer temperatures in the late first century BC; the Roman Empire saw, by and large, favourable rainfall and temperatures, followed by a period of much greater climatic instability, including lower temperatures, in the late third to late sixth centuries. Given Malanima's emphasis on the significant economic effect that a rise or fall in average temperatures of even 1°C could have, it therefore becomes important to ask: to what extent, and how, do these northern European data relate to the Mediterranean? Are they part of a more global trend in climate, that affected the Mediterranean world, and, in its time, the Roman Empire, as a whole?

Interestingly, increasing precipitation in the fourth to sixth centuries shown in the northern European data seems to parallel a phase of increased runoff and erosion which has been identified (but not closely dated) in sites along the Tunisian coast by the Franco-Tunisian coastline survey which identified a late Roman erosive peak which the researchers attributed to climate rather than anthropic causes.⁸ But the continental European and Mediterranean climates are different and should not be expected to track each other precisely; and McCormick's paper in this volume reminds us that there is not a close correlation between the northern European data and Mediterranean written records. We need much more work on Mediterranean climate data—large-scale analyses of tree-rings, to compare with the northern European study, and a coherent programme of pollen analyses, especially from regions around the southern shores of the Mediterranean. Nonetheless, a new synthetic review of multiple series of proxy climate

⁶ Cf. Wikander 2008; Wilson 2012b.

⁷ Büntgen et al. 2011.

⁸ Slim et al. 2004, 251–253.

data, while identifying regional variation, underscores some broad correlations between climate and general economic performance, and some specific events.⁹ In particular, it notes that the period from the first century BC to early third century AD, coinciding with the peak of the Roman imperial expansion and apparent prosperity (from the archaeological record), was unusually favourable from a climatic point of view. Sturt Manning's reworking of some of the northern European dendrochronological data (his figs. 12–13), shows rises in both precipitation and temperature which appear to coincide with a peak in the expansion (numbers and sizes) of villas in Britain in the fourth century; this relationship is worth exploring further.

When considering the possible inter-relationships between climate and history, attention has until recently largely been focused largely on catastrophes and problems, especially the fall of the Roman Empire, and the large-scale population migrations of late antiquity, for example the migrations of the Huns and Avars discussed in Ed Cook's chapter in this volume.¹⁰ But the tree-ring-based climatic reconstruction by Büntgen et al., and the wider multi-proxy syntheses in this book by Sturt Manning, and elsewhere by McCormick et al., remind us of the significance of the Roman warm period in Europe, which coincided with a period of general economic prosperity in the Roman world from the first to the mid-third century AD. Clearly climate is not a monocausal explanation for the success of the Roman Empire at its peak, but it does rather look like one of many contributing factors. The fall of the Roman Empire was not of course not a single event, but more of a process. What emerges as remarkable from the new climate evidence, *if* it is applicable to the Mediterranean too, is how resilient the Roman Empire was through the third century AD, because it now seems as though, in addition to everything else thrown at it in the course of that century, the Roman Empire also had to contend with a marked deterioration in climate which will have put agricultural production, and therefore the economy at large, under additional stress.

CLIMATE, SETTLEMENT AND THE ECONOMY

The relationship of the expansion and contraction of settlement, as detectable by archaeological survey, to climatic change is still very unclear. Do we see favourable climatic conditions leading to expansion, or was settle-

⁹ McCormick, Büntgen et al. 2012.

¹⁰ E.g., in a popular vein, Keys 1999.

ment expansion underpinned by better irrigation technology and greater capital investment? Were past societies at the mercy of natural events, men hopping ineffectually on the earth's crust powerless in the grip of unshakable natural forces, or were people in some control of their environment, and able to control their destiny by shaping it, at least to a degree? Paula Kouki's paper on the Jabal Harun is ambivalent on this point. So too the long-running debate over Roman North Africa is still not fully settled; its origins date back to the nineteenth century, when some argued that Roman Africa's prosperity must have been facilitated by a more favourable climate,¹¹ while others argued that it was achieved at the price of extensive investment in artificial irrigation and water management systems.¹² What relatively little work has been done on the subject in recent decades has not resolved the question: we have a few, inconclusive pollen studies,¹³ and even the UNESCO Libyan Valleys Study concluded that it was unable to answer the question definitively; the climate in the Roman period was thought to be broadly similar to that today, although any detectable variation in ancient vegetation cover may have been due either to cultivation or to climate change, but the environment was so marginal that potentially even a small variation could have made a big difference.¹⁴ Whether there was such a variation, and whether it did make a difference, the project could not say.

As Malanima points out, a change of one degree centigrade in the average temperature affects cultivation altitudes by 100 m. Warmer climates thus mean that more upland areas can be cultivated, and cooler climates restrict the cultivated surface. Of course, things are rather more complicated than that because mountainsides are not totally abandoned when the climate becomes cooler; rather their landuse would change from vines or olives to forest, which might still be used for fuel, or timber.

What we do see, in parts of North Africa at least, is a considerable expansion of the cultivated surface as marginal lands were increasingly brought into cultivation. This is particularly apparent in the Kasserine Survey, where the Roman period saw intensive exploitation of nearly all hillsides and mountainsides, which were terraced to enable their systematic cultivation with vines and olive trees.¹⁵ Pottery from the terraced slopes dated from the first to seventh centuries AD; there was no sign of the slopes being used

¹¹ E.g. du Coudray la Blanchère 1895, 4.

¹² Gsell 1921, 56–99; cf. Shaw 1981, 380, 383, 388–390; Wilson 1997, 33–35.

¹³ Rouvillois-Brigol 1985; 1986; cf. discussion in Wilson 1997, 34.

¹⁴ Barker et al. 1983, 82–84; Hunt et al. 1985, 13; Hunt et al. 1986, 14–16; Hunt et al. 1987, 4–6.

¹⁵ Hitchner 1988, 28; 1989; 1990; 1992; 1995b.

before the Roman period, and little afterwards. Bruce Hitchner has argued that these developments reflect the kind of incentivisation to expand the cultivated area that we can see on imperial estates in the first and early second centuries AD, in the *lex Manciana* and the *lex Hadriana de rudibus agris*, which provided for rent-free periods on uncultivated land that was brought under exploitation, while newly planted trees and vines came to maturity.¹⁶ The significance to the present debate is that this expansion was happening in a climatically favourable period. Climatic warming was not necessary to enable cultivation of these hillsides, although it remains an open question whether this exploitation of marginal lands was at least facilitated by (slightly?) increased rainfall. It is possible, therefore, that the cultivation of these more marginal lands is to be explained as a result of population pressure, and perhaps economic growth, taking advantage of expanded or better connected markets, rather than as a result of climate change.

Debates over Roman economic growth are tending to countenance scenarios where there was some per capita growth from the reign of Augustus to the mid second century AD, at which point it was stopped by an exogenous shock. There are dissenting voices—Walter Scheidel, for example, argues that such growth as there was from the late Republic to the second century AD was neither sustained or sustainable but rather a by-product of the ‘peace dividend’ following the end of the Civil Wars and the unification of the Mediterranean under direct or indirect Roman control, and was terminated by Malthusian constraints.¹⁷ Yet the growth/shock scenario has found considerable favour,¹⁸ and even Scheidel has accepted that the economy received a major shock in the later second century. So far the Antonine Plague has figured in debate as the best candidate for such a shock, and this is accepted by a number of historians, though by no means all; there remains in fact considerable debate over the impact of the Antonine Plague.¹⁹ But Mike McCormick’s contribution presents data for Nile flood events extracted from papyrological records²⁰ which suggest a marked

¹⁶ Hitchner 1995a.

¹⁷ Scheidel 2002; 2009, 67–70.

¹⁸ E.g. Temin 2006; Jongman 2007a.

¹⁹ Severe: Duncan-Jones 1996; Scheidel 2002. Less severe: Bagnall 2000; 2002; Greenberg 2003; Bruun 2003; 2007. See now the various papers in Lo Cascio 2012, where the majority is in favour of the ‘severe’ opinion.

²⁰ McCormick (this volume); see also McCormick, Büntgen et al. 2012; full dataset (on which the following relies) available online as McCormick, Harper et al. 2012: ‘Geodatabase of Historical Evidence on Roman and Post-Roman Climate’ at <http://darmc.harvard.edu/icb/icb.do?keyword=k40248&pageid=icb.page496495> (accessed 16 December 2012).

change in the climate-related agricultural potential for Egypt in the mid-second century. Although the pattern of average and somewhat better than normal floods was much the same across the period, before AD 155 exceptionally good floods occurred on average one year in five, but afterwards only once every twelve and a half years; while poor or failed floods occurred every five years or so before the mid second century, but more frequently—every three years—afterwards. This deterioration in the pattern of Nile floods would have depressed agricultural production, and exposed the Egyptian populace to greater risk of famine and malnutrition, especially as the state insisted on extracting *annona* grain even in poor years. McCormick chooses AD 155 as the year dividing the two different sets of flood regimes, but AD 162 or 166 would do equally well, i.e. at around the same time as the great epidemic. Is the deterioration of the Nile flood regime an additional, or alternative, perhaps even better, explanation, for the economic troubles observed in Egypt than depopulation caused by the plague? Did the epidemic ravage a population already to some extent weakened by poorer harvests? Or are the observed discontinuities in the proxy data from Egypt which have been used to argue for the effects of the plague in fact due not to the plague but to the effects of poor harvests consequent on bad or failed Nile floods? In general, and not just in the period of the epidemic, there is in fact a striking apparent correlation with recorded incidents of flight from tax-collection—to take only the examples mentioned by Gilliam in his discussion of whether or not the Antonine Plague had a serious effect,²¹ the *anachoresis* mentioned in a document of AD 55/59²² would follow a poor decade: three consecutive years of poor or very poor flooding AD 45–47, four years of average floods (AD 49–52), three years of very poor floods (AD 53–55), a normal flood in AD 57 and a very poor flood in AD 59, with no good recorded floods in the years 45–59. Further evidence for flight from villages in the Fayyum in AD 162 correlates with a year in which the Nile flood was low;²³ the depopulation of villages in the Mendesian nome in AD 168/169 and the revolt of the Boukoloi in AD 172 or 173 can be seen to have followed a series of bad years:²⁴ a very poor flood in 166, an average flood in 167, three successive poor years in 168–170, and an average flood again in 171 (data for 172 and 173 themselves are not available).²⁵

²¹ Gilliam 1961, 240–242.

²² *P. Graux* 2 = *Sammelbuch* IV, 7462.

²³ *P. Berl. Leihg.* 7.

²⁴ Mendesian nome: *BGU* 903.

²⁵ Data from McCormick, Harper et al. 2012.

The Nile flood records, which ultimately reflect rainfall in the Nile's head-water catchment area in Ethiopia and Central and East Africa, remind us that events affecting the environment outside the Mediterranean world may have repercussions for the Mediterranean too—either directly through transport of precipitation, or less directly through their effects on neighbouring populations. Büntgen et al. have drawn renewed attention to the links between climate and the migrations of late antiquity in northern Europe.²⁶ Recent research on the Garamantes of the Libyan Sahara has emphasised how the incipient urbanism, oasis agriculture and long-distance trading contacts with the Roman world were underpinned by irrigation from subterranean *foggara* systems tapping groundwater based on *foggara* irrigation; and when these irrigation systems failed in late antiquity the nexus of urban settlement and long-distance trade collapsed.²⁷ The precise chronology remains uncertain, as does the question of to what extent this failure was due to over-exploitation of a fossil, non-renewable, aquifer, or to decreased local rainfall as a result of climate change;²⁸ but the environmental changes that led to the break-up of Garamantian power over the Libyan Sahara seem to have had broader repercussions, and may be linked to migrations out of oases in the northern Sahara, and the incursions of Libyan tribes into late Roman, Vandal and Byzantine North Africa in the fourth to sixth centuries AD.²⁹

ANCIENT UNDERSTANDING OF THE HYDROLOGICAL CYCLE

To explore the extent to which past societies might have been able to control and manage their environment, it is perhaps useful to review Roman understanding of the hydrological cycle.³⁰ Vitruvius (*fl.* c. 50–26 BC) gives a description of the hydrological cycle based on Greek sources (he cites Theophrastus, Timaeus, Posidonius, Hegesias, Herodotus, Aristides and Metrodorus).

²⁶ Büntgen et al. 2011.

²⁷ Mattingly 2003; Wilson and Mattingly 2003; Mattingly and Wilson 2003; Mattingly and Wilson 2010; Wilson 2012a.

²⁸ Cremaschi et al. 2006 argue for a dramatic drop in Saharan rainfall in the Ghat region around AD 450; but their dendro-record is based on a single tree for large stretches of the reconstruction, and cannot be regarded as reliable without cross-matching (Sturt Manning, pers. comm.). Moreover, rainfall in the Ghat region may have had little connection with that in the Wadi al-Ajal, the Garamantian heartlands, 400 kms. to the north-east.

²⁹ Fentress and Wilson forthcoming.

³⁰ The following section is based on Wilson 1997, 35–39, which treats the sources at greater length.

Rainfall is caused by the air acquiring moisture from the ground and from springs, rivers, marshes and the sea, which is evaporated by the heat of the sun. It is carried upwards in the form of clouds, and is precipitated when the clouds strike mountains (*de Architectura* 8.2.1–4). Long-distance transfer of water resources is described in the case of south winds, which desiccate hot areas and redeposit the moisture elsewhere (8.2.5). Water (including melt-water) infiltrates underground and emerges as springs (8.1.7).

Seneca (c. 5/4 BC–AD 65) devotes Book 3 of his *Naturales Quaestiones* to a discussion of water, rivers and springs, and two partially preserved books (4A and 4B) to the Nile and to hail and snow. A lost work of Theophrastus seems to have been one of his main sources. He discusses a number of observed phenomena, but his explanations for them are influenced by Stoic notions of cosmic flux and are often less accurate than those of some of his predecessors. He plays down the role of groundwater, believing that rain never penetrates the earth to a depth of more than ten feet, and most of it is carried off to the sea by rivers (*Nat.* 3.7.1). He notes that in arid regions wells may be driven 200 or 300 feet before encountering water, and calls this *aqua viva*, ‘living water’, as it cannot have come from rainwater infiltration (3.7.3–4). Rivers are formed not by groundwater but by condensation of air in hollows within the earth (3.9.2–3); rain does not cause rivers, but only makes them flow faster (3.11.6). He does not give an account of the hydrologic cycle, and states that the sea has its own springs (3.14.3). However, some observations are more accurate; deforestation causes the emergence of springs because water is no longer consumed by vegetation (3.11.3–5).

Pliny (AD 23/24–79) indicates an awareness of seasonal variations in groundwater levels; he says that wells generally run dry about the rising of Arcturus (17th September), and that springs vary their discharge according to season (*Nat.Hist.* 31.xxviii.50–51). Earthquakes may cause springs to dry up or appear (31.xxx.54). Springs can also arise as a result of deforestation, and tree cover inhibits erosive streams (31.xxx.53). Pausanias (fl. c. AD 160) displays awareness of the effects of agriculture on increasing erosion and the concomitant downstream deposition of alluvial fans (8.24.10–11). Certain ancient writers therefore display a basic understanding of the hydrological cycle, the formation and behaviour of groundwater, and of the effects of agriculture and deforestation on erosion. Knowledge was available to tap aquifers, locate springs, use dams to recharge groundwater reserves, and exploit mineral or thermal properties of water. The principle that subterranean reservoirs could store winter rains for discharge in the summer months was at least theoretically understood, even if Aristotle had refuted it

as the explanation for the origin of rivers (*Mete.* 349b3–15). There was clearly much interest in different types of water, their properties and their effects on health.

We are familiar with the fact that Near Eastern, Greek and Roman hydraulic engineering was capable of remedying local deficiencies in water availability by the transfer of water resources from elsewhere via aqueducts, which could in the Roman and Byzantine periods achieve extraordinary lengths—98 km for the second-century aqueduct feeding Carthage from the springs at Zaghouan, later increased to 132 km by the addition of tributaries in the Severan period; and the aqueduct that supplied Constantinople, completed in AD 373, had a main channel of 227 km with a tributary of 41 km.³¹ Duncan Keenan-Jones' discussion of the Serino aqueduct in Campania in this volume emphasises the capability of Roman engineers not only to effect inter-basin transfers of water (something common in fact to many Roman aqueducts), but also to think on a regional scale in terms of supplying several cities. The highly urbanised region of the Bay of Naples demanded extraordinary solutions to the problem of supplying such a large and nucleated urban population with water.

Case Study: Controlling Tiber Floods

A further illustration of the developing ancient understanding of total river basin management, which enables us to go further than the information given by the ancient authors mentioned above, is provided by the history of Roman attempts at controlling the flooding of the Tiber. Duncan Keenan-Jones' chapter in this volume discusses two of the big proposed flood relief schemes, under Caesar and Tiberius; here I want to consider them in the light of the overall chronological development of attempts at Tiber flood control. In the last thousand years the Tiber has flooded to levels of 10–13 masl on average every year, and above 13 masl on average every two years.³² As Keenan-Jones notes, the wetter conditions suggested by climate reconstructions for between c. 100 BC and AD 200 would have exacerbated this pattern in the Roman period. The lowest-lying areas in antiquity, most exposed to flooding, were the Campus Martius, the Velabrum, forum, the Circus

³¹ Generally: Wilson 2008a. Constantinople: Crow et al. 2008; Crow 2012, 40.

³² Le Gall 1953, 62–65; Lugli 1953, 61–69; Ammerman 1990, 637; Belati 1999; Aldrete 2007.

Maximus and Emporium areas below the Aventine, and Trastevere. The Pons Sulpicius had to be rebuilt on numerous occasions following damage by flooding.³³

From the period of the Etruscan kings through to the High Empire, progressively more ambitious and effective means of flood control were considered, some of which were not carried out for political reasons. Coring work in the forum and the Velabrum by Albert Ammerman has shown that in the sixth century BC the ground level in these areas was artificially raised by between 1 and 4 m by dumps containing gravel, tuff fragments and anthropic material, as a landfill scheme intended to bring the ground surface above the level of many floods.³⁴ The ground surface would have needed to be raised some 2 m in the centre of the valley, to bring it to around the 9 m contour level that would put it above all but the worst floods. Ammerman estimates that at least c. 10,000 m³ of fill would have been needed; possibly twice that amount. Such an exercise implies considerable manpower resources, and may have occurred over a period of several years; Ammerman notes parallels with other major landscaping works under the Etruscan kings. If the construction of the Cloaca Maxima to drain the forum area went hand in hand with raising of its surface above the level of the Tiber floods, the emphasis in the ancient writers on the arduous nature of the *corvée* work becomes easier to understand.³⁵

These early solutions, involving considerable landscape transformations of the forum valley, made possible the creation of a public space in what was to become the heart of Rome, and laid the foundations for the later urban development of the city. Impressive and labour-intensive as they were, their effect was to raise certain areas only above the levels of many, but not all floods; the problem of Tiber flooding had been alleviated, but not solved.

As Rome expanded in the mid and late Republic, Tiber floods began to affect a larger inhabited area. The development of the Campus Martius, started by Pompey and Caesar and further continued under Augustus, compounded the problem.³⁶ There were six severe floods in the reign of Augustus, and a further, disastrous, flood in AD 15, the year after his death. Tiberius, instead of consulting the Sibylline books as advised, appointed a

³³ Tac. *Ann.* 1.86 (23 BC); SHA *Antoninus Pius* 8; Dio Cassius 1.3.20; 27.58 and 50.8; Desnier 1998, 515, 520.

³⁴ Ammerman 1990; 1998.

³⁵ Ammerman 1990, esp. 636–645.

³⁶ Belati 1999, 13.

permanent commission of five senators, the *curatores alvei Tiberis et riparum*, who had responsibility for managing the banks of the Tiber—their duties included ensuring the dredging of the river channel and canalising its banks (marked by cippi). These measures contained some of the lesser floods, but still did not remove the problem; floods continued almost annually. Part of a bridge pier belong to the ancient Pons Aurelius, found below the Ponte Sisto in the nineteenth century, seems to have been marked with a Tiber flood gauge; it was graduated in Roman feet in reverse order, apparently therefore showing the height remaining until the river reached a danger or warning level.³⁷

Up to this point, then, we have seen the development of attempts to contain flooding within the urban zone. Fundamentally different were efforts to tackle the cause of the problem, which we see for the first time in a scheme considered by Caesar, but never put into effect. This was the construction of a relief channel leaving the Tiber near the Mulvian bridge and running around the back of the Janiculum hill, to feed back into the Tiber below the city.³⁸ Caesar's assassination prevented the scheme being carried out.

Serious flooding recurred almost annually, and throughout the course of the first century AD increasingly ambitious attempts started to deal with the root of the problem, rather than simply to contain the symptoms. After a major flood under Tiberius, a scheme was proposed to divert the Chiana, one of the Tiber's tributaries on the right bank upstream from Rome, into the Arno to reduce the amount of water flowing through Rome, and that the waters of another tributary, the Nar, should be dispersed throughout its floodplain, and the artificial channel feeding the Nar from the Velina lakes be dammed up. This provoked a senatorial debate and the scheme was successfully opposed by the local communities (Florence, Interamna, and Reate) who would have been affected by this move, using a variety of arguments both practical and religious.³⁹

At the downstream end of the Tiber Valley, Claudius' works on the new harbour at Portus included the digging of relief channels to link the Tiber to the sea, above the sharp bend by Ostia which acted as a bottleneck and caused the waters to back up, affecting the river as far upstream as Rome. Claudius' inscription makes explicit the link between the works at Portus and the risk of flooding at Rome (*ILS* 207 = *CIL* XIV.85):

³⁷ Marchetti 1892.

³⁸ Cicero, *Att.* 13.33.4; Aldrete 2007, 182–184.

³⁹ Tacitus, *Annals* I.79. Aldrete 2007, 185–188; Campbell 2012, 118–119; Keenan-Jones (this volume).

Ti. Claudius Drusi f. Caesar ... fossis ductis a Tiberi operis portu caussa emissisque in mare urbem inundationis periculo liberavit

Tiberius Claudius Caesar, son of Drusus, ... freed the city from the danger of flooding by leading canals from the Tiber into the sea in connection with the building of the harbour.

This scheme shows that Claudius' engineers evidently understood the systemic nature of flood control, and that it might be necessary to effect works many miles distant from the point at which one desired to control the floods. An additional effect of Claudius' works must also have been to reduce the extent to which Ostia was exposed to regular and severe flooding. Claudius' boast that he had liberated the city from the danger of flooding was cruelly shown to be premature by the severe flood of AD. 69, recorded by Tacitus (*Hist.* I, 86.2), and also by the inscription commemorating Trajanic works (below).

There was further raising of the ground level in the Campus Martius in the later first century AD: under Domitian the pavement of Augustus' sundial was repaved at a level 1.5 m higher than the original. Indeed, it may be that the flooding of the Tiber in this area caused the obelisk to settle out of true, explaining why Pliny says the sundial was inaccurate only 50 years after its construction. The Trajanic or Hadrianic pavement of the Pantheon lies 1.85 m above that of its Agrippan predecessor.⁴⁰

Trajan constructed further exit channels from the Tiber to the sea near Ostia and Portus; if the reconstruction of some of the missing text is correct, Claudius' measures had not been entirely effective (*ILS* 5797):

[Imp. Caesar divi] | Ne[rvae fil. Nerva] | Tra[ianus Aug. Germ.] | Dac[icus trib. pot.] ... | im[p. ..., cos. ... p. p.] | fossam [fecit | q[ua inun[dationes Tiberis | a]dsidue u[rbem vexantes | rivo] peren[ni instituto arcerentur]

Imperator Caesar Nerva Traianus Augustus Germanicus, son of the deified Nerva, ... made a canal by which the floods of the Tiber which continually troubled the city were kept away with the construction of a permanent channel.

Post-Trajanic measures seem to have been limited largely to repairs to the Tiber banks and dredging of its channel, for example under Aurelian (*SHA Aur.* 47, 1–3).

The larger flood relief schemes of the first and early second centuries AD imply a recognition that effective solutions to the problem of the Tiber

⁴⁰ Belati 1999, 16.

floods required a landscape-wide solution which addressed the whole catchment area of the river valley, and its estuary. However, political considerations prevented the most ambitious schemes (Caesar's relief channel and the Chiana diversion), which were also the most likely to have provided an effective longer-term solution, from being put into action.

THE ENVIRONMENT OF PRODUCTION

The differential costs of land, riverine and maritime transport influenced the geography of production in a manner clearly seen along coastlines and major river valleys. In the ancient Mediterranean the preferred container for long-distance transport was for centuries the amphora, although it gradually gave ground to the barrel. Ceramic amphorae were heavy, however, and their production was preferentially located along navigable rivers and near the coast. In Baetica, a major olive-oil producing region, the kilns which made the Dressel 20 amphorae in which the oil was shipped were located along the Guadalquivir and its main tributary, the Genil, and the oil was transported in skins from the farms to the kiln sites for bottling and riverine transport in amphorae down to Hispalis (Seville) and then loaded onto maritime ships for export to Rome and other distant markets. In the other major olive oil exporting regions, modern Tunisia and north-west Libya (Tripolitania), amphora production was chiefly concentrated at coastal sites which acted as the bottling centres for the produce of the hinterland.

Amphora production, and ceramic production in general, was also strongly influenced by the availability of fuel, especially important where production had been scaled up for large-scale long-distance export. The otherwise puzzling location of the large-scale southern Gaulish samian production centre at La Graufesenque may be explicable to a large degree by the ready availability of firewood (the clay deposits were some kilometres distant). In Tunisia, where firewood was scarce, and the waste from olive pressings was used as fuel, some co-location of olive oil production and amphora and cookware manufacture, often at coastal sites, is observable.⁴¹ Coastal sites also had the advantage that firewood could be imported by boat, as depicted in a mosaic from Sousse.⁴² Confirmation of the importance of a

⁴¹ Olive pressings as fuel at Leptiminus, Tunisia: Smith 2001, 434–435. Co-location of amphora and cookware production: Leitch 2011.

⁴² du Coudray la Blanchère and Gauckler 1897; Meiggs 1982, 10, Pl. I.6; Meiggs 1982, 529–530; Wilson 2012b, 149.

long-distance maritime trade in wood fuel comes from a second- or third-century papyrus from Tebtunis, referring to the import of Italian firewood.⁴³

William Harris' contribution to this volume discusses the extent of possible deforestation in the Greek and Roman periods, suggesting hesitantly that such deforestation as there was in classical times was probably more in the nature of land clearance, and most visible in Attica; deforestation probably increased in the Hellenistic and Roman periods but the effects of demand were to some extent offset by improved woodland management and increased long-distance maritime trade that mitigated the impact on their immediate hinterlands of the fuel demand created by large cities. His discussion emphasises the scale of ancient fuel consumption and the trade both in firewood and in construction timbers.⁴⁴ For firewood, it is not fully clear whether fuel wood was imported to certain regions because it *had* to be (i.e. was there serious deforestation in North Africa, Egypt, and the vicinity of Rome?), or because it could be, cheaply, for example as return cargoes. Robyn Veal's chapter on fuels stresses the use of charcoal as well as firewood, and shows the potential for ancient fuel studies, but we should also consider the possible uses of non-wood fuels—as mentioned above, Pompeii, North Africa and Syria have all yielded evidence suggesting that the use of olive pressing waste as a fuel in commercial ovens and kilns was common; and the use of animal dung as a fuel for purposes not requiring very high temperatures, such as domestic hearths and bread ovens, has a long history in Asia Minor and the Near East, and has been identified in Numidian levels at Althiburos (Tunisia).⁴⁵ The scale of the trade in construction timber will evidently need to be taken into account when we get to the stage of doing the tree-ring analysis for the Roman Mediterranean. What mixing of the dendro-record might it create? Can we use the tree-ring research to identify the sources of timber?

FUTURE DIRECTIONS

Our understanding of the scale and effects of ancient pollution still has a long way to go. Exemplary regional studies such as that in the Wadi Faynan, Jordan, have shown the local effects of Roman and Byzantine copper

⁴³ *P. Tebt.* II.686 (cited by Harris, this volume).

⁴⁴ Harris (this volume); cf. Wilson 2012b: 139–140.

⁴⁵ W. Brown 1820, 297–300. Althiburos (dung in an oven of the 4th–2nd century BC): Portillo and Albert 2011, 3232.

smelting and mining activities there, and how the soil still remains massively polluted, with long-term effects on animals and the human population of the region even today.⁴⁶ The identification of anthropogenic pollution in Greenland ice cores in the 1990s, principally from copper and lead/silver working, has attracted much attention, but the original studies used relatively few samples and produce graphs with very spiky peaks and troughs.⁴⁷ Much work on ice-cores in both the Arctic and Antarctica has been done since the original studies, and we can soon expect to have a high-resolution record of atmospheric pollution over the last 3,000 years, with annual or sub-annual resolution and an absolute dating precision of ± 2 years, that could enable further investigation of levels of ancient mining and metallurgical activity, and their environmental impact.

Most of the papers in this volume concentrate on processes and long-term trends, rather than catastrophic events. Volcanic eruptions or their effects are mentioned in passing in several papers (McCormick, Keenan-Jones), but earthquakes are not mentioned at all. These perhaps deserve greater consideration in environmental history—not to overemphasise catastrophe in itself, but rather to assess the relative effects of sudden and long-term change. There is much work to be done here, ranging from assembling more comprehensive lists of ancient earthquakes (including not just those mentioned in ancient sources but also those inferred from archaeological excavations) and volcanic eruptions (again, including those detected principally through tephra or sulphate deposits in ice cores), to the consideration of large socio-economic effects.⁴⁸ To what extent were ancient states able to respond to natural disasters such as earthquakes or volcanic eruptions, to afford disaster relief, or rebuilding, and how far did they try to do so? The clustering of earthquakes in the fourth–sixth centuries AD known to geologists as the ‘Early Byzantine Tectonic Paroxysm’, deserves greater attention in considerations of Byzantine history.⁴⁹ Does a particular clustering of earthquakes within this period and around the ‘big one’ of 21 July AD 365 with its epicentre off western Crete, help to explain the notable peak in rebuild-

⁴⁶ Barker et al. 2007.

⁴⁷ Original studies: Hong, Candelone, Patterson and Boutron 1994; Hong, Candelone, and Boutron 1994; Hong, Candelone, Patterson and Boutron 1996; Hong, Candelone, Soutif, and Boutron 1996; Rosman et al. 1997. Relation to ancient economic history: McCormick 2001, 53; Wilson 2002a, 25–29; 2007; 2009; de Callataÿ 2005; Jongman 2007a, 188–189; Scheidel 2009.

⁴⁸ Lists of earthquakes: Guidoboni 1989; Guidoboni et al. 1994; Ambraseys et al. 2005; cf. Ambraseys 1994; 2006; Nur 2010. Much archaeological evidence remains to be assessed and added (e.g. a probable earthquake at Euesperides, Benghazi, 262–250 BC: Wilson 2003).

⁴⁹ Stiros 2001.

ing inscriptions between AD 360 and 375, especially in North Africa?⁵⁰

The ice core record, which has trapped sulphates emitted by volcanic eruptions, can also help with reconstructing links between ancient eruptions and climate. A recent study of Scandinavian settlement and tree rings argued that the Norse myth of the *Fimbulwinter*, the harsh winter that precedes the end of the world, with three years without summer, and the breakdown of social order, with successive wars and brothers killing brothers, reflects the dust veil event of AD 536, observable in the dendrochronological record of Scandinavia and in the abandonment of numerous settlements in the mid sixth century.⁵¹ The dust veil event had a global reach, affecting the Mediterranean (Procopius speaks of the sun shining only weakly for 18 months) and China.⁵² The Greenland ice core record shows extremely high sulphate levels for AD 533–534 ± 2, which suggests that the dust veil event of 536 was caused by a volcano,⁵³ possibly the Tierra Blanca Joven (TBJ) event of the Ilopango volcano in El Salvador.⁵⁴ Through a combination of ice core studies, volcanology, archaeology, and the analysis of Norse poetry, we are now able to draw a link between the mythological motif of the *Fimbulwinter* and, possibly, a volcano in Latin America.

And lastly, what of the marine environment? The effects of eustatic and relative sea-level change have been identified along the coasts of Italy and Tunisia,⁵⁵ and at other localised points—chiefly harbours and major ports—,⁵⁶ but systematic study of the Mediterranean coastline, and especially Algeria and Libya where relatively little work has been done, is needed to assess the regional impact of sea-level change on coastal settlement and economies, including the effects on the viability of ports. Conversely, although a certain amount of attention has been paid by historians and archaeologists to human impact on the terrestrial environment, what of the impact on the marine environment and fish stocks. Did the large-scale fishing practised in the Roman period have any measurable impact on the size of particular fish species, or on fish stocks or populations?⁵⁷

⁵⁰ Cf. Wilson 2011, 163–165.

⁵¹ Gräslund and Price 2012.

⁵² Gunn 2000.

⁵³ Larsen et al. 2008.

⁵⁴ Dull et al. 2001; Dull et al. 2010.

⁵⁵ Schmiedt 1972; Slim et al. 2004.

⁵⁶ Blackman 1973.

⁵⁷ Cf. Marzano 2013 on the scale of Roman fishing.

The highest resolution reconstructions of ancient climate currently available pertain to northern Europe where the dendrochronological record is best, but the situation for the Mediterranean is improving, with multi-proxy reconstructions now being produced, albeit often reliant on lower-resolution data. There is a need for more data and higher-resolution studies for the Mediterranean, North Africa and the Near East if we are properly to address the question of how far climate affected history and settlement, and explore to what extent were ancient populations able to combat adverse climate change with adaptive agricultural technologies and water management systems, such as the runoff farming in the pre-desert of Tripolitania or in the Negev. Nevertheless, exciting advances have been made in recent years at an accelerating rate in the fields of ancient climate reconstruction, dendrochronology, and the studies of environmental pollution trapped in ice cores, and the increasing interplay between these kinds of science and historical research is opening up new possibilities for profoundly deepening, and perhaps even transforming, our understanding of the relationship between history and the environment.