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Panzootics, Pandemics and Climatic Anomalies in the Fourteenth Century

Bruce M. S. Campbell

1 Alternative explanations of the fourteenth-century crisis

Demographic and economic trends and processes during the century famously described by Barbara Tuchman as the ‘calamitous fourteenth century’ have long been matters of debate. At issue are, on one hand, the long-term consequences of sustained population growth under conditions of a finite supply of land, essentially organic methods of reproduction, and predominantly animate sources of energy, and, on the other, the role of the natural hazards of extreme weather and infectious disease. It is a debate, therefore, in part about the relative historical importance of economic versus biological factors, or, as it is often characterised, between endogenous versus exogenous forces and agents. While both are regarded as relevant, opinion is divided as to which was the more important prime mover.

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1 I am grateful to Professor Bernd Herrmann for the invitation to present this paper to the Göttinger Unwelthistorischen Kolloquium. Previous versions of it were given at The Queen’s University of Belfast, Bocconi University, Milan, and as one of the 2010 Linacre Lectures, Linacre College, Oxford. It has since been given at the Wissenschaftskolleg zu Berlin during my period as a Fellow there in 2010-11. Comments and suggestions by those who have heard it in its various incarnations have proven invaluable in its revision for publication.

2 Tuchman (1979). For the debate see Aston and Philpin (1985); Campbell (1991); Hatcher and Bailey (2001); Rigby (2006).

3 Campbell (2010a).

Since England is better documented than most other European countries during this period, its experience has tended to bulk disproportionately large in the debate.\(^5\)

Certainly, population trends in England from \(c.1200\) to \(c.1500\) present a striking chronology (Figure 1).\(^6\) First, during the thirteenth century, the population increased by over half, growing at an estimated 0.5 per cent \textit{per annum} between 1190 and 1250, slowing to 0.3 per cent \textit{per annum} 1250—90, but thereafter, following the famines of the mid 1290s and 1315—21, registering little further net increment. Next, over the course of the fourteenth century, and mainly within the narrow space of three generations, between \(c.1315\) and \(c.1390\), all of these gains (and more) were eliminated, so that by the end of that century the population had been more than halved and was back down to the level of the early twelfth century. Nor did decline stop there, for the population continued to shrink until at least the mid-fifteenth century and only thereafter began very slowly to recover. By \(c.1520\) the population was still approximately 25 per cent smaller than it had been a dozen generations earlier \(c.1190\). Patently, major shifts must have taken place in the

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5 See, for example, Aston and Philpin (1985).
6 For the estimates employed in this paper see, Broadberry \textit{et al.} (2010b).
balance struck between fertility, mortality and migration in order to have produced such profound alterations to the pace and direction of change. These population trends were mirrored by equally remarkable changes in the purchasing power of the wages paid to unskilled agricultural labourers (Figure 1). Until the mid-thirteenth century real wage rates appear to have held up reasonably well but, thereafter, as the population rose so rates of pay fell in value. They sank to their historical nadir at the climax of the Great European Famine of 1315—21, just after the population had passed its medieval peak and at a time when heightened mortality and depressed nuptiality had elevated deaths over births. In the wake of the famine possibly due to a modest increase in nominal wage rates, and further aided in the 1330s by low prices consequent upon abundant harvests and in the 1340s by a financially induced price deflation, real wages improved marginally. The gain, however, was tiny compared with that which followed the successive plague outbreaks of 1348—49, 1361—62, 1369 and 1375 with their cumulative mortality of at least 50 per cent. Notwithstanding government attempts at wage restraint, as the population shrank and labour became ever scarcer, so real wage rates rose. These gains became especially pronounced following the Peasants’ Revolt of 1381, partly because the Statute of Labourers was less rigorously enforced but also because a run of unusually bountiful harvests depressed the prices of bread and ale. By the middle of the fifteenth century real rates of pay had attained their medieval maximum, peaking at the very time that the national population had dwindled to its minimum (Figure 1). Between their lowest level in 1316 and their highest 150 years later in 1464, wage rates paid to agricultural workers had more than quadrupled. Such gains, however, are almost certainly exaggerated and should be compared with an estimated doubling of GDP per capita between these two dates.

How is the tripartite trend of growth, crisis, and decline in population and its counterpart trend of decline, crisis, and recovery in real wages to be explained? Three broad schools of thought may be identified: economic, biological and ecological.

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7 For an exploration of these demographic relationships on a single large manor see Razi (1980).
8 Clark (2007a).
11 For wage rates see Clark (2007); Munro (2009). For harvests see Campbell (2007); Campbell (2010b): 24–8. For money supply see Munro (2009). Between 1330 and 1345 money supply per capita approximately halved.
12 Clark (2007), but see Munro (2009).
13 Campbell (2010b): 28; Campbell (forthcoming).
14 For a critical evaluation of the difference between wage rates and earnings see John Hatcher, ‘Unreal wages: long-run living standards and the “golden age” of the fifteenth century’, forthcoming. I am grateful to Professor Hatcher for letting me read this unpublished paper. For GDP per capita see Broadberry et al. (2010a).
Economic explanations have tended to draw their theoretical inspiration from the writings of Malthus, Ricardo, Marx, and Adam Smith. Typically, they stress variant combinations of (a) the dynamic but unequal relationship between population and available resources and tendency towards diminishing returns, (b) the mediating influence of prevailing socio-property institutions and the incentives and disincentives these gave to development of and investment in improved technology, and (c) the compensatory economic gains to be derived from the growth of trade and commerce. For all their differences of ideology and emphasis, the notion that endogenous anthropocentric processes were primarily responsible for the crisis that succeeded growth and the prolonged contraction which then followed the crisis, is an idea common to all economic explanations. For subscribers to this reading of developments, reconciling a growing population with an essentially fixed supply of resources without sacrificing living standards, especially when prevailing institutions discouraged enterprise, investment, and productivity growth, is regarded as the central dilemma which this particular pre-industrial society failed to resolve. To have done so it needed to reap far greater gains from trade but as yet England’s commercial development was too limited to offset the diminishing returns taking place within the agrarian sector of the economy. In fact, rising transaction costs in international trade may actually have reduced trade flows, further restricting employment opportunities, especially in the service and manufacturing sectors, constraining living standards, and, via a reverse multiplier effect, tightening the spring of the Malthusian trap. Eventually, it is argued, land became so scarce, incomes so reduced, and real wages so low that further population growth became unsustainable and it was this ‘crisis of over-population’ that provided the essential preconditions of poverty, malnutrition, and over-crowding for the sequel mortality crises of famine and plague, which occurred when the population was at a maximum and living standards had been reduced to a minimum. Famine and plague therefore assume the role of Malthusian positive checks. The ensuing demographic contraction redressed the imbalance between population and resources, thereby raising the real value and bargaining power of labour and inducing a sustained rise in wages. Because real wage rates basically mirrored the aggregate trend of population, falling when the population expanded and rising when the population contracted, economic historians such as Gregory Clark have dubbed this a ‘Malthusian economy’.

Certain features of this tripartite chronology of population and real wages do not, however, comply with Malthusian logic or its economic alternatives. For instance, on strictly economic reasoning the rising real wage rates of the late

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15 Hatcher and Bailey (2001).
16 Aston and Philpin (1985).
17 Munro (1991); Epstein (2000).
18 Postan (1966); Titow (1969).
19 Clark (2007b).
fourteenth and early fifteenth centuries should have acted as a positive stimulus to new household formation and thus prompted a vigorous recovery of population. Likewise, if mortality was a function of living standards, it should have fallen as GDP per capita and real wages both improved. For population to have remained so low when real wages were for so long so high was economically perverse.20 Nor can the extreme bad weather responsible for the repeated harvest failures that caused the Great European Famine, or the pathogens which killed with such ferocity during the Black Death and its aftershocks, be convincingly accommodated within an explicitly economic framework since both originated within the natural world.21 Rather, the Black Death demonstrates the powerful and independent role which microbes were capable of performing in the unfolding human saga. David Chambers was among the first to make this point and, in 1967, dissent from the then prevailing economic orthodoxy. In his view, ‘for random biological reasons’ ….. ‘the long-term trend in population change was non-economic in origin’.22 Jared Diamond’s recent claim that ‘because diseases have been the biggest killers of people they have been the decisive shapers of history’ offers a radical restatement of the same verdict.23

According to this biological school of thought, the initial period of population increase, when growth was maintained notwithstanding a sustained and serious erosion of living standards, was a product of the relative absence of dangerous pathogens. Over time, rates of growth certainly slowed as opportunities for new household formation dwindled and deteriorating nutritional and hygiene standards elevated economically induced mortality, nevertheless, the latter merely curbed the rate of population growth, it lacked the power to reverse it. The upshot was higher densities of population. Meanwhile, commercial, administrative, religious, and military links were being elaborated.24 In these ways, pre-conditions ideal for rapid diffusion of new infectious diseases were created. Until these biologically naïve and vulnerable populations were exposed to a new and deadly pathogen, however, this Malthusian deadlock could have lasted indefinitely.25 It was the introduction of plague to this situation which therefore broke the status quo and initiated a new demographic era.26 In place of a thickly-peopled pre-plague world of declining living standards but relatively low disease mortality, a far more thinly-peopled post-

20 Hatcher (2003).
22 Chambers expounded this view in the Kent Co-operative Endowment Lectures, published posthumously in 1972 as Population, economy, and society (p. 87). 30 years later Chambers’s views were endorsed by Lee and Anderson (2002): 217, when they concluded, with respect to English population trends after 1540, ‘most of the long-term change in fertility and mortality was non-Malthusian in origin (that is, unrelated to changes in wages), and instead was a response to other influences such as weather, disease, or institutional change’.
26 For a case study see Campbell (1984).
The plague world came into being of rising living standards and massively increased disease mortality, in which each new generation of biologically naïve individuals provided the basis for a renewed outbreak of plague, thus endlessly thwarting and postponing any full demographic recovery.

The agents of this biological transformation were twofold. First, a deadly cattle panzootic reached Britain from mainland Europe in 1319 and over the next 18 months destroyed an two-thirds of the national bovine herd. Key casualties were the oxen upon which the agricultural sector relied for a majority of its draught power, and the milk cows, so essential for the breeding of replacement draught animals but also a supplier of vital protein to an increasingly malnourished population. Cattle plague — most likely the Rinderpest virus — thus struck at the population indirectly, by undermining the reproduction of staple foodstuffs. A generation after the panzootic had ended the damage it inflicted had still not fully been made good. Then, before reconstruction could proceed further, a second plague struck, this time of humans. It had already devastated populations in many parts of Europe and between late summer 1348 and the end of 1349 it is now estimated that it killed at least 40 per cent of England’s population, with the death toll rising to over 60 per cent in the worst hit communities. Sequel plague epidemics followed in 1361—62, 1369, and 1375, and collectively impelled the population on what proved to be an irreversibly downward course. Unsurprisingly, the labour of those who survived gained significantly in real value so that nominal and real wages both rose.

Either of these two plagues would make a strong case for the historical significance of disease; together, that case becomes compelling. Whence they came and why exactly they broke out when they did are not, however, questions that have attracted much attention. Chambers, for instance, was content to ascribe their irruptions to ‘random biological reasons’ and seek little further explanation of them. Yet, as with the outbreak of a war, an explanation is required, the more so as neither plague was a new disease. Both had long coexisted with bovines and humans but mostly within certain broad geographical confines or ‘inveterate foci’. What was new in the fourteenth century was their sudden expansion out of these established reservoirs and invasion of entirely new areas with disastrous consequences for their virgin-soil populations of bovines and, via rodents, humans. Many generations before something similar may have occurred, endowing a few fortunate individuals with a degree of inherited immunity. Nevertheless, most lacked any resistance, which is why the resultant death tolls of at least 65 per cent of cattle and 40 per cent of humans were so high. Of course, neither could have

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28 Broadberry et al. (2010b).
31 Chambers (1972): 87.
spread before the essential preconditions for their diffusion were in place, namely high densities of susceptible populations closely integrated through trade and other linkages, but this is a necessary and not sufficient explanation of their respective pan-European diffusions. There has to be a reason why diseases which had long lain dormant and in large parts of Europe were actually extinct, suddenly became active again.

Since publication in 1984 of Graham Twigg’s *The Black Death: a biological appraisal*, diagnosis of what the Black Death was has become a contested issue. Among the alternative diagnoses on offer, the clearest case for the Black Death as an intrinsically exogenous event is that made by palaeoecologist Mike Baillie, who has argued from a range of environmental and historical evidence that it originated as biological fallout from a close encounter with a comet on St Paul’s Day, January 1348. It is difficult to imagine anything more randomly biological than a new infectious disease reaching Earth from outer space. Recently obtained aDNA evidence extracted from the dental remains of fourteenth-century plague victims excavated at St Laurent-de-la-Cabrerisse (southern France), Hereford (England), and Bergen-op-Zoom (The Netherlands) has, nevertheless, re-instated *Yersinia pestis* (i.e. bubonic plague) as the pathogen responsible for the Black Death. This relocates human plague within a complex biological, zoological, and environmental nexus comprising the pathogen (a bacterium), its host (wild and commensal rodents), the vector(s) by which it was spread (fleas and possibly lice), its human victims, many of whom became carriers and spreaders of the infection in its pneumonic form, several varieties of domesticated animal, including camels and cats, plus birds which also spread the disease, and the climates and physical and human environments within which they all co-existed and inter-acted and by which, in their different ways, they were affected. For Nils Stenseth, ‘this complicated epidemiology necessitates considering plague ecology within its full ecological web’: further, ‘the dynamics of the host species are ‘profoundly influenced by climate variation’.

Historically, major plague outbreaks have coincided with volcanic dry fogs, El Niño events, and other climate anomalies. This suggests that the Black Death may have been strongly influenced by environmental conditions and especially by sudden changes in those conditions. More generally, ecological theory stresses the inter-connections between the physical, chemical, biological and human components of ecosystems, including the single greatest ecosystem of them all, the Earth System. Because of these inter-connections, change in any one of these components typically has multiple effects that cascade through the wider system in

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32 Contrast Cohn Jr. (2002b); and Theilmann and Cate (2007).
34 Haensch et al. (2010).
36 Stothers (1999); Zhang et al. (2007); Ari et al. (2010).
37 Scheffer Marten (2009).
complex ways. When critical thresholds are exceeded, change can be particularly abrupt and on occasion may result in a ‘bifurcation’ or change in the system from one state to another. A case can be made that this is what happened over the course of the fourteenth century, when a high-pressure equilibrium of high and rising population numbers was replaced by a low-pressure equilibrium of reduced and slowly dwindling numbers. Real incomes were lowest in the earlier state and life expectancy shortest in the later. To understand why this shift came about requires a consideration of the physical, biological and human environments and in particular the point of overlap and intersection between them, since that was where the mainspring of change was most probably located. In short, it suggests that movements of population and real wages over these three centuries may be better understood within an ecological than either an economic or biological framework.

2 The physical environment

Scant attention has so far been paid to the contribution of climatic and other physical environmental factors to the fourteenth-century crisis, partly for want of reliable evidence of sufficient chronological precision. The latter is no longer the case. Spurred on by contemporary concerns about climate change, research into palaeoclimates has advanced apace. As a result the respective characters and chronologies of the so-called Medieval Climate Anomaly (MCA) and Little Ice Age (LIA) have been brought more sharply into focus, along with the transition between them. High-resolution temperature series have now been reconstructed from a variety of proxy sources — tree rings, speleothems, corals, varves in lake and ocean sediments, ice cores, pollen series, and a variety of historical sources — and calibrated against instrumental records spanning the recent past. For the last millennium, and sometimes longer, these are available at a variety of geographical scales, including land and sea. A recent reconstruction of Northern Hemisphere land and sea-surface temperatures by Michael Mann and his team is particularly comprehensively documented and, in its broad trend, correlates well with alternative reconstructions.\(^{38}\) Plainly apparent is a mean hemispherical drop of almost 0.5° Celsius from the warmth of the MCA, at its peak in the late tenth century, to the coolness of the LIA, at its worst at the beginning of the eighteenth century (Figure 2). The mid-thirteenth century represents the halfway point on that downward trend and a century later temperatures plunged to a level barely 0.1° Celsius above the LIA minimum. The thirteenth and fourteenth centuries thus mark a pivotal period in the transition from one climate era to another.

\(^{38}\) Mann et al. (2008). Recent alternative temperature reconstructions include Moberg et al. (2005); Briffa et al. (2008); Loehle and McCulloch (2008); Ljungqvist (2010). Most reconstructions are available as datasets from: World Data Center for Paleoclimatology, 325 Broadway, Boulder, Colorado, Unites States. WWW: http://www.ncdc.noaa.gov/paleo/paleo.html.
Figure 2. Reconstructed Northern Hemisphere temperature anomalies expressed in relation to the long-term mean, AD 500 – 1900. 

Figure 3. Variance of Northern Hemisphere temperatures and North Atlantic sea-surface temperatures, AD 500 – 1900 (51-year periods smoothed and indexed against their respective long-term means). 
Ecosystems approaching a critical threshold commonly exhibit an increase in variance. Figure 3 shows the variance of Northern Hemisphere temperatures and North Atlantic sea-surface temperatures, calculated over 51-year periods and indexed against their respective long-term means. Over the 1,400 years 500 to 1900 the level of variance in both series varied by a factor of four or five. Particularly notable peaks in variance occurred in the 950s, 1090s, 1350s, 1440s and 1670s, of which the greatest, in terms of both hemispherical and sea-surface temperatures, was that of the 1350s. Distinctive features of the latter period included a marked see-sawing between high-amplitude surface cooling and warming events in the North Atlantic, the advent of repeated bouts of intense cold over Greenland, centring on 1303, 1320 and 1353, and surges in sea-ice formation off the northern coast of Iceland especially in the 1310s, 1330s and 1370s. In Britain the variance of British Isles oak growth, English grain yields, and Scottish speleothem band widths also all attained a collective temporal peak between 1344 and 1353. Since these proxy measures of environmental conditions are all independently derived they leave little doubt that in the Northern Hemisphere generally, and north-western Europe and the North Atlantic specifically, the middle years of the fourteenth century were a time of extreme instability.

Key features of the MCA had been a strong El Niño Southern Oscillation (ENSO) in the tropical Pacific, with a predominance of cold La Niña over warm El Niño conditions in the eastern Pacific; a strong Asian and Indian Monsoon which ensured delivery of significant levels of seasonal precipitation in most years; and a strong North Atlantic Oscillation (NAO) which meant that northern European winters were typically both mild and wet due to the dominance of a strong westerly airflow. Until the mid-thirteenth century, notwithstanding an overall reduction of at least 0.2°C Celsius in Northern Hemisphere temperatures since the warmest phase of the MCA, there is little sign of any weakening in these influential components of the global climate system (Figure 2). In fact, in the 1240s and 1250s the available evidence implies that the ENSO, Asian Monsoon, and NAO were all at near maximum strength (Figures 4—6). In all three cases, however, this represents a final efflorescence of these conditions for, over the next 200 years and with gathering momentum, each progressively weakened as part of the profound global climate reorganisation which accompanied transition to the LIA.

Developments within the Pacific Ocean, the World’s greatest and deepest equatorial water body, were of especially far-reaching significance, for they affected the climates and weather systems of the Americas, Australasia, and much of Asia, with repercussions over an even wider area. During the MCA, when warm global

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40 Dawson et al. (2007); Kobashi et al. (2010); Massé et al. (2008).
42 Graham et al. (2010); Sinha et al. (2011).
temperatures prevailed, the ENSO had remained strong, generating predominantly cold sea-surface temperatures in the eastern Pacific which blocked humid oceanic air from penetrating adjacent regions of North and South America. The upshot in much of the American west and the Pacific littoral of Peru and Chile had been a series of mega-droughts, one of the longest and greatest of which centred on 1253.43 Thereafter, however, as dendrochronological evidence demonstrates, the extent and intensity of droughts in the American west eased and were never as great again (Figure 4). Indeed, by the 1320s weather conditions in this extensive semi-arid region were more humid than they had been for over 500 years, probably because of the temporary dominance of warm El Niño conditions in the eastern Pacific. From the mid-fifteenth century such conditions became a regular phenomenon, so that during the LIA rainfall levels in much of the American west were substantially higher than those experienced during the MCA. These developments were paralleled at corresponding latitudes in South America. Analysis of cores taken from the Quelccaya ice cap in Peru and ocean-shelf sediments off the coasts of Peru and Chile, indicate a significant rise in precipitation levels from the 1260s.44 These culminated in a major flood event c.1300, the greatest since the onset of drought conditions c.800.45

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43 Cook et al. (2004); Rein et al. (2004); Mohtadi et al. (2007).
44 Mohtadi et al. (2007), 1062.
45 Magilligan and Goldstein (2001).
On the opposite side of the Pacific, where hitherto warm sea-surface temperatures were cooling, precipitation levels trended in the opposite direction, bringing drought to regions long accustomed to and dependent upon regular, heavy monsoon rains (Figure 5). In South Vietnam a Palmer Drought Severity Index derived from the ring widths of the cypress *Fokienia hodginsii* growing in Bidoup Nui Ba National Park reveals the onset of increasingly serious drought conditions from the 1270s. Brief but intense low humidity events occurred in the 1290s, 1310s and 1320s but these were soon eclipsed by the mega drought which commenced in the late 1330s and persisted with little respite until the mid 1370s. The ecological repercussions of such a profound transformation of weather conditions must have been profound. This precipitation failure also shows up in the reduced ring widths of *Larix sibirica* (larch) growing in Mongolia and Siberia but is etched most clearly in the annual band widths of speleothems formed in Wanxiang Cave, north-central China, and Dandak Cave, north-central India (Fig. 5). Although formed over 3,000 kilometres apart, these two speleothem records reveal a remarkably consistent and coherent story: an initial weakening of

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46 Buckley *et al.* (2010).

The Fourteenth Century Crisis

the Asian and Indian monsoons in the 1270s was followed by a more prolonged and pronounced failure in the 1290s, probably the worst for over 600 years, which proved to be the precursor of far greater droughts to come.48 The most persistent and serious of these commenced c.1336, grew to a peak of intensity in the 1350s, and did not finally relax its grip until the late 1370s. Other mega droughts followed, whose destructive and destabilising environmental effects were compounded by sporadic mega-wet monsoons and the flooding they generated.49

The changing strength and character of the Indian monsoon had effects felt as far away as central China and reflected ocean—atmosphere interactions in the Indian Ocean as much as the Pacific. The strength of convection over the Indian Ocean in turn influenced circulation patterns at more northerly latitudes via its effect on the jet stream.50 Climatic conditions over the Atlantic were therefore not unconnected to those over the Indian Ocean; they were also affected by sea-surface temperatures in the Cariaco Basin and by the strength of deep ocean currents emanating from the Pacific Ocean. Until the 1240s this combination of influences ensured a strong pressure difference between Iceland in the north Atlantic and the Azores in the mid Atlantic and thus a positive NAO (Figure 6). That meant the winter dominance of a strong westerly air-stream over northern Europe, which kept far colder, drier, polar and continental air masses at bay. Because humid oceanic air was deflected to the north, southern Europe and North Africa, in contrast, languished under relatively arid conditions.51

During the MCA the annual band widths of a speleothem from north-western Scotland imply the predominance of mild, wet, winter weather across northern Britain, while in Morocco, a Palmer Drought Severity Index derived from the growth rings of Atlantic cedars confirms that in North Africa drought was a persistent feature of the period.52 Combining these two records yields a proxy index of the relative strength of the NAO, in terms of the magnitude of the difference in sea-level pressure between Iceland and the Azores.53 As Figure 6 shows, the NAO remained consistently positive throughout the twelfth and thirteenth centuries and was still strongly positive up to the 1310s, but in the 1320s and 1330s it weakened significantly and although it revived during the 1340s it never fully regained its former strength. In the 1350s and 1360s it weakened again and then in the 1440s and 1450s, for the first time in 400 years, became negative. From then on it alternated between positive and negative modes, with the latter predominating during the coldest decades of the LIA when the winter westerlies took a more southern course, bringing storms and heavier rainfall to the hitherto

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48 Sinha et al. (2011).
49 Sinha et al. (2007); Buckley et al. (2010).
50 Graham et al. (2010): ‘disturbances to the Northern Hemisphere jet stream over southern Asia ... can efficiently propagate over great distances and tend to amplify over the North Atlantic’.
51 Esper et al. (2007).
52 Proctor et al. (2002); Esper et al. (2007).
53 Trouet et al. (2009).
Figure 6. North Atlantic Oscillation derived from Scottish speleothem band widths and a Palmer Drought Severity Index for Morocco derived from Atlantic cedars, 1050 – 1950. *Source: Trouet et al. (2009).*

parished lands of the Mediterranean while exposing northern Europe to prolonged incursions by polar and continental air masses. It was during the earlier period of transition, in the fourteenth and fifteenth centuries, as rival oceanic and continental air masses ebbed and flowed across northern Europe, that the variance of Northern Hemisphere temperatures and North Atlantic sea-surface temperatures were both greatly amplified (Figure 2).

Most palaeoclimatologists agree that variations in the output of solar energy were a key ingredient of all these climatic developments. A recent reconstruction of solar irradiance by Gilles Delaygue and Edouard Bard (Figure 7) shows that irradiance output was significantly lower during the LIA than it had been during the MCA. It follows that declining irradiance levels during the thirteenth century (especially the latter part of that century when major emissions of volcanic aerosols in 1258/9, 1268, 1275, 1285 and 1341/3 veiled out and reflected back some of the incoming radiation) are likely to have been responsible for reduced warming of the tropical Pacific and Indian and Atlantic Oceans then taking place, with all the implications that this had for ocean—atmosphere interactions, sea-level pressure,

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54 Jiang et al. (2005); Mann et al. (2005); Moberg et al. (2005), 615-17; Wang et al. (2005); Bard and Frank (2006); Seager et al. (2007); Zhang et al. (2008); Trouet et al. (2009); Berkelhammer et al. (2010); Graham et al. (2010). For a dissenting view see Cobb et al. (2003), 274-5.

55 Delaygue and Bard (2010) supersedes Bard et al. (2000): the correlation between the two irradiance series for the years 868—1936 is +0.897.
Figure 7. Total Solar Irradiance reconstructed from Beryllium-10 ice-core records from Antarctica, 850 – 1950. Source: Delaygue and Bard (2010).

the force and direction of winds, patterns of precipitation, and much else.\textsuperscript{56} Punctuating the broad multi-centennial trend in irradiance levels were a number of shorter-term episodes when solar output was much diminished and, as Solanki \textit{et al.} estimate, sunspot activity effectively ceased.\textsuperscript{57} The first of these, following the brief Oort Minimum of \textasciitilde{1010}—1050, was the Wolf Minimum of \textasciitilde{1282}—1342, which ties in well with the decisive weakening at that time of the most important core elements of the MCA. After a short but impressive revival in solar activity during the second half of the fourteenth century, the Spörer Minimum of \textasciitilde{1416}—1534 coincided with the first full onset of most of the main climatic features that would dominate the LIA, whose coldest phase occurred during the well-known Maunder Minimum of \textasciitilde{1654}—1714. These conditions returned during the Dalton Minimum of \textasciitilde{1790}—1830, which remains the most recent of these episodes of marked solar inactivity.\textsuperscript{58} It should be noted that, on these datings, for 180 out of the 250 years from the 1280s to 1530s sunspot activity was either much reduced or absent altogether, so it is hardly surprising that this period witnessed many of the most fundamental changes in the Global climate system, with far-reaching consequences for flora, fauna, microbes, and humans.

\textsuperscript{56} Gao \textit{et al.} (2008).
\textsuperscript{57} Solanki \textit{et al.} (2005).
\textsuperscript{58} The dates of these solar minima are those given by Stuiver and Quay (1980).
3 The biological environment

These often abrupt changes in climate with their associated disruptions to and dislocations of ecosystems are directly relevant to the fourteenth-century outbreaks of cattle plague and human plague, for ‘climatic variations and extreme weather events have profound impacts on infectious disease’.\(^5^9\) This is because, as biologists Rosalie Woodruff and Charles Guest explain, ‘in the case of vector-borne diseases, an increase or decrease in rainfall can have a profound effect on local ecologies’ and ‘in some cases weather fluctuations may cause either host or vector populations to migrate to areas outside of their habitat, in this way bringing them in contact with non-immune human populations’.\(^6^0\) Crucially, not only did the panzootic and pandemic irrupt and spread when climatic instability was either approaching or at a peak, notably in the second and fifth decades of the fourteenth century, but each coincided with a distinctive climatic anomaly, when environmental conditions were anything but normal.\(^6^1\) The latter is brought out most clearly by the respective dendrochronologies of Old World and New World trees (Figure 8).

Insofar as trees growing in the Old World (i.e. EurAsia) and the New World (i.e. the Americas and Australasia) were affected by common variations in global temperatures and incoming levels of solar irradiance, their chronologies tended to develop in parallel. Thus, from 1200 to 1314 there is a positive correlation of +0.46 between these two macro chronologies, rising to over +0.8 between 1230 and 1255 when the ENSO, Asian Monsoon, and NAO were all at near maximum strengths (Figures 4—6). Likewise, from 1342 to 1600 a positive correlation again prevailed between the two growth series, this time of +0.39 with a maximum of +0.9 during the 25-year period 1510—35. Given the diversity of local growing conditions and botanically different growth requirements between the tree species encompassed by these two chronologies, these are impressively high correlations. It is therefore all the more remarkable that during the hundred years from 1288 to 1387 the correlation between these two chronologies swung from strongly positive (1288—1314 correlation of +0.763), to strongly negative (1315—41 correlation of -0.714), and then back to strongly positive again (1342—87 correlation of +0.847) (Figure 8). Intriguingly, the cattle panzootic irrupted, spread, and burnt itself out between 1315 and 1325 during the negative-correlation phase, and it was during the second and stronger of the two positive-correlation phases, between 1346 and 1375, that the four successive waves of the human pandemic emerged, spread, and died.

\(^5^9\) Patz et al. (2005): 311.
\(^6^0\) Woodruff and Guest (2000): 92.
\(^6^1\) Campbell (2010b).
In the case of the environmental context of the panzootic, it was obviously unusual for trees on opposite sides of the World to exhibit such divergent responses to prevailing environmental conditions and to deviate so markedly from their normally positive relationship. First, from c.1315 until c.1322, the inversion favoured Old World trees, then, from c.1322 until c.1341, New World trees displayed the greater growth (Figure 8). The strange fluctuations in sea-surface temperatures within the North Atlantic seem to have formed part of this episode, which began in 1315—18 when unusually warm Atlantic surface waters sustained some of the most persistently wet weather with which agricultural producers right across northern Europe have ever had to contend.62 As Dawson et al. observe, ‘the famine and the ‘Great Rains’ of AD 1315–1318 as well as the early 1330s across Northwest Europe, appear to have coincided with an exceptional interval of “overheating” of Atlantic surface ocean waters that provided a source of moisture for prolonged summer rains as well as winter storms’.

### Notes


63 Dawson et al. (2007): 431.
preceding discussion of the physical environment, this was no random configuration of the weather since it occurred at a threshold stage in the transition from MCA to LIA when proxy measures around the World register a marked heightening of instability. For instance, at EurAsia’s north-eastern extremity, in Siberia, the variance of the annual ring widths of Larix Sibirica soared during these years and in 1316 ± 25 was higher than at any time before or since during the last two millennia. As is clear from the chronologies of Old and New World trees, this was a climatic anomaly of approximately seven-years duration and it has been termed by Neville Brown the ‘Dantean Anomaly’ since it ended in the year of Dante’s death.

Historically, these conspicuously disturbed climatic conditions are most obviously associated with the Great European Famine of 1315—21, when three out of seven harvests were outright failures (1315, 1316, and 1321) and a fourth (1317) was seriously sub-standard. Prices testify to the acute scarcity of staple provisions: 1316 is the dearest year on record for grain and salt (both of which required dry, sunny weather for their production), while 1318, 1320 and 1323 were exceptionally dear years for herrings, which depended upon fair weather for their catching and salt for their curing. Unsurprisingly, ordinary workers experienced a devastating collapse in the purchasing power of their already meagre wages (in no other time of want have the wages of farm workers bought less). And, to compound their misery, with less to harvest and process, the demand for labour shrank. Nor was this all, for it was precisely when the weather was most disturbed and the ecological dislocation at its greatest, in 1314—16, that the cattle panzootic surfaced and, from a probable source in Bohemia, began its deadly and contagious diffusion westwards across Europe. It reached northern France in 1317, Brabant, the Low Countries, and Denmark in 1318, England around Easter 1319, Wales and Scotland by 1320, and Ireland in 1321, where it raged until 1325 when it finally abated, its force spent. As an English contemporary lamented: ‘then came there another sorrow that spread over all the land (a thousand winters there before never came none so strong to bind all the poor men in mourning and in care), all the

64 Larix Sibirica: data supplied by M. G. L. Baillie, 26/1/2010. In Siberia over the last two millennia the variance of larch ring widths has peaked on four separate occasions at intervals of 300—400 years, in the 210s, 540s, 950s, and, most recently and prominently, in the 1310s. In Siberia, on the evidence of this proxy measure, the years from 1290—1340 emerge as the least stable 50-year period of the last 2,000 years. Their instability is all the more conspicuous because the variance of larch growth subsequently shrank dramatically to a temporal minimum in the early fifteenth century, and ever since has remained well below the peak level of the early fourteenth century.
67 Clark (2008).
68 Campbell (2009).
69 Newfield (2009).
cattle died straightaway and made the land all bare so fast, came never wretchedness into England that made men more aghast'.

Bovines, of course, were an indispensable source of milk, meat, tallow, hides, manure and, above all, draught power. In England they supplied a clear majority of all kinetic energy deployed on the land hence any collapse in their numbers and failure in the supply of replacement beasts was potentially disastrous to output from the vital arable sector. That the panzootic was both highly contagious and deadly is not in doubt. Across England large numbers of extant manorial accounts provide detailed enumerations of demesne livestock at Michaelmas (29 September) 1318, 1319 and 1320. These totals reveal passage of the disease with chilling clarity: over the 2 years between Michaelmas 1318 and Michaelmas 1320 the national demesne cattle herd sustained a loss of around two-thirds. This huge reduction arose from sales as well as deaths, since many demesne managers responded to the crisis with the panic selling of animals in a desperate effort to realize at least a portion of the massive capital value of their herds. In a market crowded by sellers and abandoned by all but the most imprudent buyers, the sale price of cattle collapsed relative to prices of other livestock. That many of the live beasts thus disposed of subsequently either succumbed to the disease or were butchered is nevertheless likely. Nationally, across all classes of producer, probably in excess of ½ million working oxen were eliminated during the 18 months that the disease raged in England. Since each ox possessed the muscle power of six men, this was equivalent to a manpower loss of at least 3 million adult males in a society with an adult male population of probably less than 1½ million.

In the absence of conclusive scientific evidence, the panzootic has been provisionally diagnosed as rinderpest, an acute and usually fatal viral disease, principally of cattle. This disease usually ran its course, from incubation, to the emergence of symptoms, and finally death, in 9—21 days. Death rates during outbreaks could be as high as 100 per cent and usually only a small minority of animals recovered. Immunity was acquired by the few that did, although infertility

70 Dean (1996), lines 409-14: ‘Tho com ther another sorwe that spradde over al the lond/ A thusent winter ther bifore com nevere non so strong/ To binde alle the mene men in mourning and in care/ The orf deiede al bidene, and maden the lond al bare/ Com nevere wrecche into Engelond that made men more agaste’.

71 In 1300 oxen probably outnumbered agricultural horses by 2 to 1 and in aggregate contributed 4% more horse power: Campbell (2003). See also Langdon (1986).

72 Campbell (2010b): 25. Between 1317/18 and 1320/21 estimated national numbers of demesne oxen fell by 46%, bulls and cows by 68% and immature cattle by 60% (calculated from a national database of manorial accounts).


74 The national population is unlikely to have numbered more than 4.75 millions, of which adult males probably accounted for less than one third: Broadberry et al. (2010b).

75 Alternative diagnoses are discussed by Newfield (2009), who concludes that rinderpest is the most likely cause of the plague. In October 2010 the United Nations Food and Agriculture Organisation provisionally announced final elimination of the rinderpest virus following a sustained veterinary campaign: http://www.fao.org/news/story/en/item/46383/icode/
sometimes resulted and the milk output of cows was often impaired. Post-plague herds were therefore reduced in size, fertility and productivity. Rebuilding them was consequently a protracted process especially as further losses often resulted from recurrences of the disease. The virus itself was disseminated by close direct or, sometimes, indirect contact between animals and typically was spread to new areas by movement of infected animals. Since oxen were widely used for carting and hauling and cattle of all sorts were exchanged and traded over sometimes quite considerable distances, as well as being favoured targets of thieves, rustlers and war bands, it is easy to see how and why the fourteenth-century outbreak eventually infected such a wide geographical area. It also spread fast, at a rate of 5—6 kilometres per week and 290 kilometres per year, taking just 5 years to reach Ireland from Bohemia. The feat of surmounting the physical obstacles presented by the Channel and Irish Sea was probably achieved with the unwitting help of humans. In the absence of effective preventive and curative measures, the panzootic ran its natural course unchecked until it eventually burnt itself out.

Whence had the panzootic originated? Outside of Britain the cattle plague has received scant attention and historical references to it are mostly tantalizingly vague. Cattle can die in large numbers from an assortment of infections and for a variety of reasons, including harsh weather and a dearth of fodder and forage, hence mention of ‘heavy mortalities’ of cattle does not necessarily denote a disease event, let alone an earlier outbreak of rinderpest. Substantial cattle losses from mostly unstated causes are, however, recorded (in retrospective order) on Jutland and in southern Sweden in 1310—08; Alsace, southern Germany, Poland, and the Russian steppes in 1300—1298; Persia in 1295—91; north China in 1306, 1301, and 1288; and Mongolia between 1331 and 1288. If any or many of these mortalities constitute earlier manifestations of the same cattle plague, they hint at a disease which spread from east to west across EurAsia and whose first outbreaks in Asia coincided with the significant weakening of the Asian Monsoon which began in the late 1280s and grew in severity during the following decade (Figure 5). In the Siberian larch chronology 1287—89 were years of minimal growth, in the Indian Dandak Cave speleothem record 1287 is the single driest year on record since AD 890, 1287—88 also stands out as exceptionally dry in the south China Dongge Cave speleothem record, while the Palmer Drought Severity Index for South Vietnam identifies 1291—92 and 1295—96 as years of unusually low

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76 For evidence of reduced milk yields following the cattle plague see Slavin (2010): 170-72.
77 On the Kent estates of Canterbury Cathedral Priory oxen were restored to their pre-plague numbers within 10 years, but restocking with cows and their followers took longer; all bovines then suffered a major setback in 1333-34, from which the estate had still not recovered when the Black Death struck in 1349: Campbell (2010c): 48-9. The 1333-34 cattle mortality also shows up at a national level, along with another in 1345-46: Campbell (2010b): 25.
78 Hanawalt (1979); McNamee (1997).
79 Newfield (2009); Slavin (2010). I am grateful to Professor Janken Myrdal for the reference to cattle losses in southern Sweden.
rainfall. The environmental difficulties of these years are writ large in reduced tree growth throughout both the Old and New Worlds (Figure 8). No doubt they arose in part from onset of the Wolf Solar Minimum around 1282, and were reinforced by atmospheric loading with volcanic aerosols consequent upon eruption of Mount Etna in 1284/5 (Figure 7). Anomalous climatic conditions are thus just as much implicated in the timing of these earlier cattle plagues as they are in the later panzootic. In the 1280s and 1290s symptoms of these altered environmental conditions show up right across EurAsia.

Similar mystery surrounds the geographical origin of the Black Death, notwithstanding the far greater scrutiny it has received as an event. The plague’s first certain historical appearance was in the lands of the Golden Horde, between the Caspian and Black Seas in 1345—46. By 1346 the Genoese port of Caffa on the Crimean coast had fallen victim to the contagion, partly as a result of the reputed hurling of corpses into the city by the besieging and plague-ridden Mongol army. Those who then took ship and fled the city, its siege and pestilence, transported plague across the Black Sea possibly to Constantinople and certainly on to the Sicilian port of Messina, where plague broke out in October 1347. Thence it spread in all directions via the arteries of Mediterranean maritime commerce, which meant that the pathogen’s eventual invasion and conquest of the Near East, North Africa and most of western Europe was assured. Within 12 months of the Sicilian outbreak it had reached southern England and eastern Ireland, the next year the rest of England and Ireland, plus France, the Rhineland and Norway became infected, followed by Scotland, Germany, Denmark and Bohemia in 1350, Poland in 1351, and finally Russia in 1352—53.

Considering that *Yersinia pestis* (bubonic plague) is a vector-borne bacterial infection, the Black Death spread exceptionally fast, covering 15—40 kilometres per week, traveling as much by sea as by land, and moving at five times the speed of the earlier cattle plague and double that of the railroad-assisted early twentieth-century Indian pandemic. Once a population became infected the disease’s clinical passage was swift, usually a matter of just months, and as the frontline of infection advanced it left burnt out and traumatized communities in its wake. No socio-economic group was spared but the clergy, through their greater exposure to infection on account of their ministration to the sick and dying and communal

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80 Berkelhammer et al. (2010); Wang et al. (2005); Buckley et al. (2010).
81 Sinha et al. (2011).
82 Norris (1977); Benedictow (2004): 44-54.
83 Wheelis (2002).
84 Benedictow (2004); Christakos et al. (2007).
85 Christakos et al. (2007).
86 For a reconstruction of the impact of the plague upon one East Anglian community see Hatcher (2008).
lifestyle, may have suffered particularly heavy losses. For society as a whole it is now thought that death rates averaged over 40 per cent and in the worst affected communities exceeded 60 per cent. Fleas were the principal vector by which the pathogen was spread from wild to commensal rodents and thence to humans, while human fleas and lice were very likely involved in transferring the bacterium between humans. In its deadlier pneumonic form, plague could also be spread directly from person to person. Humans, and the ships, carts and wagons in which they and their merchandise were transported, were clearly instrumental to diffusion of the bacterium, since its pattern of spread was from port to port, town to town, and village to village. Whether rodents and fleas were also active participants in this diffusion process remains unclear. Through these means human plague eventually infected a far wider geographical area than the earlier cattle plague, for all that the latter, as a viral infection, had a simpler mechanism of transmission, was highly contagious, and, over land, cattle naturally moved over far longer distances than rodents.

It is the prehistory of the pandemic, before its emergence in 1345/6 in the land of the Golden Horde to the west of the Caspian Sea, that remains the great unresolved puzzle. Many have speculated that the plague originated much further east. Scientific support for this view has recently been provided by Morelli et al. from their decoding of the Yersinia pestis genome. In their opinion ‘Yersinia pestis evolved in or near China and spread through multiple radiations to Europe ... leading to country-specific lineages that can be traced by lineage-specific SNPs [Single Nucleotide Polymorphisms]’. Certainly, China is known to have experienced major epidemics in the 1340s and 1350s although so far there has been no suggestion that these were outbreaks of plague. In fact, in John Norris’s carefully considered opinion ‘historical records are such as to cast strong doubt on the various attributions to China, India or Central Asia as the source of the Black Death in the fourteenth century’. From a comprehensive review of the secondary literature, the sole clue that he found to an outbreak earlier than that of 1345/6 is dated 1338—39 and relates to Issyk-kul, 2,500 kilometres east of Caffa on a subsidiary northern branch of the Silk Road in Kirghizia (al. Kyrgyzstan) in central Asia. Here, there is archaeological evidence from headstones in two cemeteries of a concentration of deaths in 1338—39 with a statement on three of the headstones that the deaths were due to ‘pestilence’. There is, however, no certain proof that the pestilence was Yersinia pestis. Consequently, Norris, and more recently Ole Benedictow, argued that the mid-fourteenth century plague probably

88 Benedictow (2004); Christakos et al. (2007); Spinage (2003).
89 These speculations are critically reviewed in Norris (1977).
90 Morelli et al. (2010): 1140.
originated not far from where it makes its first definite appearance in the historical record, somewhere near the Caspian Sea in southern Russia or, maybe, Kazakhstan, where plague remains endemic and in the wild the great gerbil is its principal host.\textsuperscript{93}

The date of the Issyk-kul ‘pestilence’ is nevertheless intriguing for it is synchronous with onset of the great Asian mega-drought of c.1336—74, when the Asian and Indian monsoons failed repeatedly (Figure 5). It may have been the ecological trauma arising from this that caused either host or vector populations to migrate to areas outside of their customary habitat, thereby bringing them into contact with biologically virgin populations of commensal rodents and humans and igniting the pan-continental pandemic which has become known as the Black Death. Alternatively, if the 1338—39 Issyk-kul mortality crisis is a false lead, plague may not have been launched upon its deadly course until sometime in the early or mid 1340s, shortly before its first documented appearance in 1345/6. Again, these are environmentally significant dates. The early 1340s mark the end of the strange growth inversion between Old World and New World trees and beginning of a major downturn in tree growth across the Old and New Worlds, the most prolonged of the last 800 years (Figure 8). That downturn was most pronounced between 1344 and 1348, the very years when the pandemic broke out and started to spread.\textsuperscript{94} It was also between 1342 and 1354 that annual variations in Northern Hemisphere temperatures and North Atlantic sea-surface temperatures both peaked (Figure 3), as did the variance of British Isles oak growth, English grain yields, and Scottish speleothem band widths, with the clear implication that environmental stress levels across wide areas of the Northern Hemisphere were approaching a maximum.\textsuperscript{95} Indeed, shortly thereafter the drought conditions that had been building across Asia attained their greatest intensity (Figure 5), hemispherical and global temperatures sank to a temporal minimum (Figure 2), and temperatures over central and western Greenland plunged to levels rarely if ever experienced since.\textsuperscript{96} Was this conjunction of abnormal physical and biological events merely coincidence or were climate and disease ecologically in league with each other, and for the second time within the same catastrophic half century? The circumstantial evidence that climatic anomalies, and the ecological dislocation consequent upon them, were integral to irruption of both the 1315—25 panzootic and 1345—53 pandemic is certainly compelling.

\textsuperscript{93} Norris (1977); Benedictow (2004): 44-54; Davis \textit{et al.} (2004); Stenseth (2008).
\textsuperscript{94} Baillie (2006), 27-39; Campbell (2010a), 302.
\textsuperscript{95} Campbell (2010b): 18.
4 The human environment

Insofar as humans were responsible for creating the pre-conditions that made it possible for these successive pan-continental epidemics to happen, they were unwitting accomplices to both major disease events. For the cattle and human plagues to have ignited so effectively and spread so fast and so far required high densities of susceptible and mobile bovine and human populations. Across Europe demographic growth and agricultural expansion during the twelfth and thirteenth centuries had brought such conditions into being. The increase of England’s population from c.1.7 million in 1086 to perhaps 4.75 million by 1290 is a particularly well-documented but far from unique example of the doubling and trebling of population densities which took place over these 200 years. Over the same period processes of colonisation, reclamation, and land-use change probably doubled the country’s arable area, whereby raising demand for draught oxen and the herds needed to reproduce them. As population densities built up and the amount of farmland per capita declined, more intensive forms of agriculture were perforce adopted. In particular, development of specialist dairy herds became a feature of many of the most advanced and integrated mixed-farming systems. These dairy producers sold off surplus male calves to cattle rearers elsewhere, who bred them up and, in turn, sold them on to either arable farmers lacking sufficient pastoral resources to rear their own draught beasts or urban butchers for fattening and then slaughtering. A single male animal might therefore change hands several times over the course of its lifetime. Cattle in ever-greater numbers thus moved between farms, regions, and countryside and town. Across Europe expanding numbers of markets and especially fairs sprang up to handle this trade, thereby creating the commercial infrastructure which in due course facilitated diffusion of the rinderpest virus throughout the pastoral and mixed-farming regions of northern Europe.

Establishment of arteries and institutions of local, regional, national, and international trade and commerce created much the same opportunities for dissemination of Yersinia pestis, whose contagious spread followed international and national trade routes. Until the commercial revolution of the twelfth and thirteenth centuries, and the heavy maritime and road traffic that it generated, the

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97 Broadberry et al. (2010b); North (2007).
98 The total area of arable — land sown with grain, field legumes, grain/legume mixtures, root crops, green crops, industrial crops, small fruit, ley crops (including temporary grass in rotation), and bare fallow — grew from just under 6m. acres in 1086 to an estimated 12¾m. acres in 1290.
100 Abu-Lughod (1989) 'has traced the rise, from the end of the twelfth century, of an incipient world system that, at its peak in the opening decades of the fourteenth century, involved a vast region stretching between northwest Europe and China. ..... It had newly integrated an impressive set of interlinked subsystems in Europe, the Middle East (including the northern portion of Africa), and Asia (coastal and steppe zones)' (pp. 352-53).
opportunities had not existed for rapid and long-distance transfer and diffusion of hosts, vectors, and microbes.\textsuperscript{102} Creation of an integrated network of markets, towns and ports rectified that, as did growing economic dependence upon the market by all social groups. Towns came into being where there had been little or no urban life before, as, for instance, in the north of England and much of Wales, Scotland and Ireland.\textsuperscript{103} Elsewhere, established cities grew significantly in size — London, for instance, almost quadrupled in population to become the second largest Christian city north of the Alps after Paris, which was twice its size — to make easy targets for the plague bacillus.\textsuperscript{104} Especially important to the plague’s spread from country to country were Europe’s proliferating and expanding port towns, through which merchandise, traders and travellers flowed, all of them potential carriers of the disease and its vector, the flea. From the ports, in turn, the disease spread to their hinterlands in a classic pattern of contagious and hierarchical diffusion via the wider commercial networks to which these gave access; thus England was penetrated via the ports of Melcombe and Bristol and Ireland via Dublin and Drogheda.\textsuperscript{105}

In later centuries the leading Italian cities led the way in developing public health measures intended to reduce the risk of plague outbreaks, including enforcement of a strict 40-day period of quarantine.\textsuperscript{106} When quarantine procedures failed at Marseille in 1720 the French authorities endeavoured to contain further spread of the epidemic by preventing all movement of people and goods out of the port.\textsuperscript{107} Such measures were born out of long and hard experience. Fourteenth-century civic authorities and governments, however, with no prior exposure to, or comprehension of, plague, were caught unawares and had no administrative means of combating the infection. Like the earlier panzootic, the pandemic therefore ran its course unchecked. Moreover, its passage was all the more destructive because these were virgin-soil populations which, in northern Europe at least, had not been exposed to \textit{Yersinia pestis} for centuries, if ever. That prior exposure made a difference to age- and sex-specific mortality levels is evident from the fact that death rates fell progressively in the sequel epidemics of 1361—62, 1369, and 1375 and to some extent became disproportionately concentrated in those groups that were biologically the most naïve, notably the young.\textsuperscript{108}

Far from hindering, humans may actually have aided and abetted diffusion of these deadly pathogens. It was, for instance, via biological warfare waged by the

\begin{thebibliography}{9}
\bibitem{102} Lopez (1976); Brinnell (1993).
\bibitem{103} For example Britnell (1996); Britnell (2004): 138-57.
\bibitem{105} For reconstructed patterns of diffusion see Christakos \textit{et al.} (2007).
\bibitem{107} Biraben (1968).
\end{thebibliography}
Mongols at the siege of Caffa that the European plague pandemic began.\textsuperscript{109} War has always been an ally of infectious disease and, as John Munro has documented, the fourteenth century was a time of proliferating and escalating warfare, as faction fought with faction and state with state.\textsuperscript{110} For instance, in 1319 and 1320 it was baggage trains supplying armies on England’s beleaguered Scottish border that helped take the cattle plague north. Cattle raids mounted by Scottish war bands then inadvertently brought the virus to Scotland, with whose predominantly pastoral economy it then played havoc.\textsuperscript{111} Thence, or possibly from England or Wales, it crossed what should have been the cordon sanitaire of the Irish Sea, to Ireland, where it raged from 1321—25, thriving on the breakdown of central authority, heightened feuding, and general social and economic dislocation that followed the Scottish invasion of 1315—18 and its accompanying famine.\textsuperscript{112} Four centuries later, when rinderpest again threatened bovine populations, the English government understood that firm action was needed if a mass mortality of cattle was to be prevented. Accordingly, it enacted measures intended to halt or restrict the movement of animals, insisted upon the destruction of herds as soon as there was the slightest hint of infection, and offered compensation to farmers as an inducement to comply.\textsuperscript{113} In 1319—20, however, in the absence of such central initiatives, husbandmen everywhere resorted to panic selling in a desperate attempt to salvage at least part of the considerable capital value of their herds. Yet dumping animals \textit{en masse} on the market is the worst thing they could have done given that transmission of the rinderpest virus thrived on close direct contact between animals and movement of infected beasts. In addition to this legal but biologically ill-advised disposal of animals, cattle stealing was rife, for the very reason that beasts were often kept out of doors, could be stolen under cover of darkness, and might be sold on at any of the country’s many markets for ready cash.\textsuperscript{114} It required only one infected beast to be taken and moved in this way for the virus to be introduced to healthy animals in new areas.

Reactions to plague could be similarly counterproductive. Not unusually, those who responded by taking flight inadvertently took the disease with them and helped infect other areas. Exactly how the Black Death achieved its exceptional speed of spread is imperfectly understood: very likely lice were involved and there has long been a suspicion that the flea vector and sometimes even the rat host may have accompanied these plague refugees, travelling in their clothes and baggage, in cargoes, and on board ships. By stimulating panic movement of people the plague, therefore, helped promote its own diffusion. Since it was almost universally interpreted at the time as an act of God, there was widespread resort to religious

\textsuperscript{109} Wheelis (2002).
\textsuperscript{110} Munro (1991): 121-30.
\textsuperscript{111} Oram with Adderley (2008).
\textsuperscript{112} Lydon (1987).
\textsuperscript{113} Broad,(1983).
\textsuperscript{114} Hanawalt (1979).
gatherings and processions.\textsuperscript{115} Yet all such congregations tended to expose fresh victims to infection and assist the plague bacillus on its destructive course. Ironically, therefore, the clergy were both in the forefront of the fight against the disease and prime agents of its dissemination, which is why death rates among the secular and regular clergy were so high.\textsuperscript{116}

Finally, endemic structural poverty undoubtedly magnified the impact of both diseases.\textsuperscript{117} By the early fourteenth century, for a combination of economic, institutional and military reasons, mounting scarcities of land and employment ensured that a high and rising proportion of European households were subsisting on no more than a bare-bones basket of consumables. In England by 1290 well over a third of households were living at this abject level of poverty and serious harvest failure later that decade and again and more devastatingly in 1315—17 greatly inflated that proportion.\textsuperscript{118} Within this most immiserated and indebted socio-economic group, those who owned and relied upon cattle for draught power, milk, and a source of income, and who typically maintained their beasts in communal herds on common pastures where they were especially exposed to infection, were exceptionally hard hit. A vital component of their livelihoods was destroyed and, already drained of capital and credit by the immediately preceding harvest failures, these petty producers must have found it almost insuperably hard to recover. Whereas large-scale seigniorial producers could afford to restock with essential draught oxen purchased from the small pool of animals which had survived the plague, this option was beyond the means of the myriad of petty producers who therefore found it far harder to reinstate arable cultivation at its pre-famine level.\textsuperscript{119} A run of bountiful harvests in the 1330s provided some temporary relief but this was offset by further heavy bovine losses in 1333—34.\textsuperscript{120} Not only was much of the previous dozen years’ painstaking rebuilding of herds undone, the damage to milk output deprived the hard-pressed rural populations of a key source of protein and placed nutritional standards of the poorest households under renewed pressure.

A society in which poverty, over-crowding, squalor, and malnutrition were so rife was obviously wide open to attack by infectious disease. In that respect, the cattle panzootic’s partial destruction of a core component of the population’s agricultural resource base helped prepare the ground for the human pandemic’s direct demographic assault a generation later. Together, poverty and malnutrition

\textsuperscript{115} Horrox (1994): 111-57.
\textsuperscript{116} Harper-Bill (1996).
\textsuperscript{117} Campbell (2005).
\textsuperscript{118} These are provisional estimates. Research into the proportion of households able to afford no more than a bare-bones basket of consumables forms one strand of the Leverhulme-funded research project (Ref: F/00215AR) ‘Reconstructing the national incomes of Britain and Holland c.1270/1500 to 1850’, directed by Stephen N. Broadberry, Bruce M. S. Campbell, Mark Overton, and Jan Luiten van Zanden, with research assistance by Alex Klein and Bas van Leeuwen.
\textsuperscript{119} Baker (1966); Livingstone (2003).
\textsuperscript{120} Campbell (2010c): 48-9; Campbell (2010b), 25.
heightened exposure to *Yersinia pestis* and lowered resistance to it. Unsurprisingly, therefore, it was the rural and urban poor who, after the clergy, experienced the highest death rates.

5 What kind of crisis?

This was clearly a crisis with human, biological, and physical components. Historians, well aware that the problems of diminishing returns to labour, declining real wage rates, faltering international trade, deepening structural poverty, and escalating territorial, dynastic and factional warfare had long antecedents, have naturally tended to give primacy to the endogenous human factors that had rendered society so calamity sensitive.\(^{121}\) For them the cattle and human plagues were merely accidents that had been waiting to happen and whose transformative power derived from the calamity-sensitive constitution of society. The fact that humans and their domesticated animals were the most conspicuous victims of these disasters has further encouraged a predominantly anthropocentric view of these events. Certainly, humans had created the pre-conditions that made it possible for both to happen, in the form of high densities of biologically naïve populations closely inter-connected through a host of administrative, religious, and commercial linkages. Other predisposing human factors included widespread malnutrition and poverty; initiation of long-distance trans-continental exchange between Asia (a possible source of both pathogens) and Europe; and an increasing scale and frequency of warfare, with all the negative ramifications this had for tax levels, the purveyancing of provisions, opportunities for brigandage and piracy, and associated transaction costs, as well as the more obvious impacts arising from plunder, pillage and wanton destruction by armies.\(^{122}\) Nevertheless, panzootics and pandemics do not happen merely because appropriate preconditions exist for them. Nor do calamity-sensitive conditions necessarily beget calamities. Instead, the ill-timed activations of the rinderpest virus and plague bacillus stemmed from other forces altogether.

To contemporaries these two great pestilences were ‘acts of God’ and so they prayed for deliverance from them; to modern scientists, instead of divine wrath, two particularly dangerous microbes were to blame, namely the rinderpest virus and (as long suspected but only recently forensically proven) the *Yersinia pestis* bacterium. Today, following a concerted and sustained global veterinary campaign, rinderpest has at last been eliminated. Plague, in contrast, is re-emerging as a disease and the several strains of *Yersinia pestis* now at large annually prove lethal to rising numbers of rodents and humans around the World and especially in Africa. That major European epidemics of both should have erupted during the

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\(^{121}\) Hatcher and Bailey (2001).

\(^{122}\) Maddicott (1975); Munro (1991).
fourteenth century within a generation of each other — around 1315/16 and 1345/46 — is striking, and all the more so given that this was at a pivotal point in the transition from the MCA to the LIA when environmental stress, as evidenced by a whole range of proxy variables, was at a maximum (Figures 2 and 3). Analysis of variance shows that instability increased on almost all fronts and at a whole range of geographical scales from the 1280s to 1350s, a sure sign that the Earth System may have been approaching a critical threshold. Within this general context, each mega disease event coincided with a specific climate anomaly and ruptured when the ecological dislocation was most pronounced and physical environmental forcing was exceptionally strong. Neither was a new disease but it was at these points of acute environmental stress that each invaded entirely new areas and commenced its lethal attack upon their vulnerable virgin-soil populations. By so doing, both compounded the damage concurrently inflicted by inclement weather and serious back-to-back harvest failure. Each crisis therefore possessed physical, biological, and human dimensions. In this unfolding ecological scenario, interactions and feedbacks occurred at multiple temporal and spatial scales – from the short-term to the long-term and the micro to the macro – as change cascaded through the Earth System in complex and unpredictable ways. Such a cascading process of contingent chaotic development defies any simple law of cause and effect and is a reminder that each stage in the ‘crisis’ was unique. As with a kaleidoscope, the same set of component variables would never again be configured in exactly the same way. Indeed, advent of the rinderpest virus and *Yersinia pestis* bacterium had changed the biological status quo for good, for both were short-term biological shocks with long-term biological consequences.

These developments worked their way out over a period of approximately 200 years, from the effective end of the MCA in the mid-thirteenth century to the *de facto* start of the LIA in the mid-fifteenth century. They eventually brought about a change from one climatic, biological, demographic, and economic state to another via processes that were protracted, episodic and, ultimately, irreversible. Although the more dramatic individual elements of this unfolding chronology, such as the Great European Famine and the Black Death, might legitimately be regarded as crises, ecologically what was taking place was a process of transition and it is as such that this whole extended episode is probably better understood. Consideration of the growing body of environmental data from a variety of geographical locations demonstrates, moreover, that it was a transition with global as well as local dimensions which featured complex interactions between environment, disease and society across the known World.

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123 Campbell (2009).
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