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WINNER OF THE PCA AWARD 2015

Domesticates, disease and climate in early post-classical Europe: the cattle plague of c.940 and its environmental context

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This article begins with a synthesis of recent scholarship on the written and zooarchaeological evidence for episodic livestock mortality events in early postclassical Europe (400-1000 CE). It addresses major and minor disease outbreaks in domesticates, as well as animal mortalities associated directly with anomalous climate and extreme weather. In line with the evidence available, the focus is set on large disease outbreaks and on cattle plagues in particular. The second portion of the article attempts to identify the triggers of animal pestilences. Particular attention is given to the indirect role of climatic anomalies in the spreading of epizootic pathogens. It is argued that climate via intermediary factors facilitated the spread of epizootics. The role of anomalous climate in animal disease diffusion is explored in a case study of the cattle plague of c.940.
Keywords: epizootics, animals, disease, climate, famine

Dopo una sintesi sulla recente letteratura scientifica riguardante eventi episodici di mortalità delle mandrie nell'Europa postclassica (400-1000 d.C.), l'articolo si concentra sulle epidemie negli animali domestici e su episodi di mortalità causati da condizioni climatiche anomale ed estreme. In linea con i dati disponibili, il testo si focalizza sullo scoppio di violente epidemie, specialmente di bovini, indagando poi le cause scatenanti delle pestilenze animali, dedicando particolare attenzione al ruolo indiretto delle anomalie climatiche che, tramite fattori intermediari, avrebbero contribuito alla diffusione dei patogeni epizootici. Infine, il caso studio dell'epidemia bovina del 940 illustra il ruolo del clima nel contagio animale.
***Parole chiave**: epizootica, animali, malattie, clima, carestia*

1. Introduction

The health and disease of domesticated animals in the past has garnered little attention. Few scholars would deny that the welfare of domesticated species was crucial for preindustrial societies, but systematic research on animal health and disease in postclassical or earlier

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eras has lagged far behind that of human populations. Scholars have studied the bovine panzootics of the 18th and 19th centuries in some detail[1], but even the large pestilential animal mortalities of earlier centuries have been considered peripheral to the story of human demographics for all that the two were clearly linked[2]. Livestock provided meat, dairy, traction, fertiliser, and raw materials, such as bone, horn, fibre, sinew, skin and tallow. Their health was deeply intertwined with human health, economy, politics and society. Linkages were omnipresent. From written sources, archaeology and zooarchaeology some connections, both unexceptional and exceptional, can be teased out, but countless others remain obscure.

The linkage of animal morbidity and mortality could be both ordinary and extraordinary. The ordinary, day-to-day illness and death associated with enzootic disease is faintly visible in written sources (in offhanded remarks like that encountered in the *Capitulare de villis* (XXIII, 85) regarding a distaste for beef from diseased animals), though animal palaeopathology has begun to illuminate the baseline of animal disease in the preindustrial past (Vann, Thomas 2006; Miklíková, Thomas 2008; Thomas 2012; Bartosiewicz (with Gál) 2013). Extraordinary, excess mortality events, associated with epizootic disease, anomalous climate and food shortage, are more apparent in written sources. When animals were sick and died en masse people noticed. Then the ubiquitous dependence on animals shifted from background scenery to foreground drama, since widespread excess mortality meant significant production loss and disruption to normal human routines. Intermittent, excess mortality events, are also visible archaeologically, in the form of mass animal graves (Auxiette, Meniel 2013), and bioarchaeologically, in the form of pathogenic remnants extracted from skeletal specimens, though palaeomicrobiologists have yet to turn their attention in earnest to the history of farm-animal disease (cattle bones from a major early medieval French burial were, however, sent recently for laboratory study: Renou *et al.* 2013, p. 140). While these linkages were indirect, zoonotic farm-animal disease directly affected human populations. These zoonoses caused morbidity and mortality in livestock and colonised, and possibly spread in, human populations. Prominent recent examples include H1N1 and H5N1, swine and avian influenzas. Middle East Respiratory Syn-

[1] A sample, focusing on recent scholarship: Mullet 1946; Dorwart 1959; Faber 1962; Broad 1983; Spinage 2003, pp. 103-150, 241-262; Vallat 2009; Appuhn 2010; Hünniger 2010, 2011; Stühring 2010, 2011.

[2] The exception now is the 1314-1325 cattle panzootic: Newfield 2009; Slavin 2010, 2012; Campbell 2010a, 2010b, 2011; DeWitte, Slavin 2013.

drome Coronavirus is also possibly enzootic in dromedary camels. Early postclassical plague-scale interspecies disease events are also visible in texts and may be teased out bioarchaeologically as well.

This paper establishes linkages between livestock health and human health, through the mediums of climate, food shortage and disease in the early postclassical period (400-1000). It engages the growing scholarship on late antique and early medieval climate, and it builds on recent proposals that early medieval disease outbreaks in humans, notably the initial occurrence of the Justinianic Plague, were triggered by, or associated with, climatic anomalies (Baillie 1994, p. 212; McCormick 2003, pp. 20-21; Arjava 2005, p. 76; McCormick *et al.* 2012, pp. 198-199). The paper has three parts. The first surveys recent scholarship on written and zooarchaeological evidence for livestock mortality events. Major and minor disease outbreaks, as well as weather- and famine-related animal mortalities are addressed. In line with the evidence available, the focus is set on large disease outbreaks and on cattle plagues in particular. A few notable events appear to have been zoonotic and some attention is given to episodes of concurrent plague-scale deaths in people and cows. Two mass cattle graves, potential bovine "plague pits", and smaller interments of cows are discussed.

The second portion of the paper attempts to identify triggers of large disease-associated animal mortalities. The role of climate is explored in particular and it is argued climatic anomalies – anomalous periods of temperature and/or precipitation years, not decades or centuries, in duration – triggered the outbreak of some major cattle plagues in the postclassical era, via their effect on food production and the socioeconomic consequences of food shortages. The triggers of many epizootics and zoonotic farm-animal plagues remain elusive. Some animal plagues appear to have been associated with human migrations and major conflicts. Many others may have been the product of unexceptional events. Ordinary phenomena such as trade in live animals, trade in bulk goods involving pack and draft animals, horizontal pastoralism, and animal-dependent human communication may have been responsible for the irruption in Europe of several of the plagues discussed below. Certainly far from every anomalous climate triggered disease outbreaks in domesticates. Indeed, the sources give no indication epizootic diseases were flowing into and circulating within Europe during some of the most severe climatic anomalies of the Early Middle Ages, the downturn of 536-544 for instance (Baillie 1994, 2008; Stathakopoulos 2003, pp. 251-255; Arjava 2005; Larsen *et al.* 2008). There was a causal connection between cattle plagues and climate, but it was dependent on intermediary factors. The difficulties inherent in untangling the relationship between epizootic disease, climate and intermediaries like famine in the early postclassical period are explored in the last segment of the paper, a case study on the cattle plague, subsistence crisis and volcanic climate forcing c.940.

Two assumptions underpin the analysis herein. It is assumed large animal plagues were spread primarily intraspecies, directly animal-to-animal. Pathogens transmitted directly between susceptible species best account for large, rapidly developing plagues that spread geographically. Plagues of cattle known to modern science capable of disseminating quickly between regions, such as contagious bovine plueropneumonia (Geering, Amanfu 2002, pp. 6-7; Food and Agriculture Organization 2002, p. 4), foot-and-mouth disease (Geering, Lubroth 2002, pp. 10-13) and rinderpest (Anderson *et al.* 1996, p. 7; Obi *et al.* 1999, pp. 5-6; Roeder, Taylor 2002, pp. 527, 530), are all transmitted primarily in this way; other indirect routes are thought to be largely ineffective. It is also assumed that the pathogens responsible for the large plagues that early medievals documented were not enzootic or native to the regions in which they were encountered. Rather, they were ecdemic or foreign and imported in live animals. Large epizootics therefore attest to movements of animals otherwise unknown in the Early Middle Ages. The disease pools in which the causative pathogens of these plagues were enzootic were probably located some distance from the regions in which the plagues were reported, considering that epizootics are episodic and animals susceptible to wide-spreading and lethal pathogens are generally unfamiliar with them[3]. The pathogens likely originated east of Europe or possibly in Africa (Newfield 2013a, pp. 75, 88-90). The animal plagues of 569-570, 809-810, 939-942 and 986-988, among others, therefore represent episodes of confluence, when two normally isolated disease pools coalesced and traded disease[4].

A final prefatory comment. The focus on interregional (or transboundary) disease and large animals plagues herein affects the role climate can

[3] Disease pools, or disease landscapes, are distinct repertoires of pathogens with shifting temporal and spatial boundaries. They are porous, vary in scale, and overlap. Multiple "micro-pools", composed of pathogens with specific environment or demographic preconditions, may exist within one "marco-pool". In other words, some pathogens are ecdemic to the overarching pool (perhaps *Variola major* in early medieval Europe) and others particular to pools within (*Plasmodium vivax* in early medieval European riverine settlements and *Mycobacterium tuberculosis* in urban centres). Macro-pools exist in opposition to each other, but may share pathogens in micro-pools.

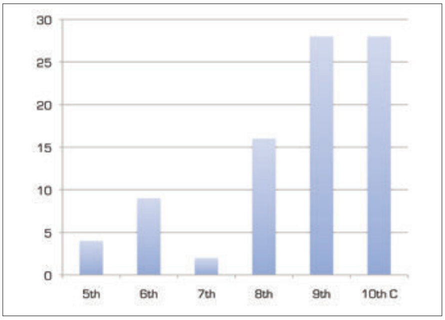
[4] Pathogens were experienced differently between disease pools. A regular widespread occurrence, but mild disease expression and low mortality may be expected where a pathogen was enzootic, and episodic widespread occurrence, severe disease and high mortality where it was epizootic. So, prior to its 2011 eradication, rinderpest was common but largely benign in enzootic zones, causing mild disease in young animals, after their inherited resistance dissipated, and very low mortality, while in epizootic zones it caused grave disease (fever, emaciation, inappetence, lethargy and profuse diarrhea) in animals of all ages and mortality in upwards of 95-100% of infected animals (Anderson *et al.* 1996, pp. 6-7, 9-11; Merck Veterinary Manual 1998, p. 543).

be given in shaping the early medieval animal disease experience. More circumscribed, regional and local, outbreaks of disease, enzootic or not, within Europe took place. On the basis of the extant written evidence it is possible most epizootics recorded in the immediate postclassical period were in fact regional or local affairs. The evidence is so meagre, however, that it is equally possible that the many brief, singular references to animal mortalities (the *boum quoque et ovium pestilentia supra modium grassata est in Francia* at 887 in the *Annales fuldenses* (105) for instance) are but glimpses of large events, plagues like those of 809-810 or 939-942.

Climate could directly affect pathogens capable of irrupting on smaller scales. Incidence and occurrence rates of arthropod- and soil-borne diseases, like anthrax, bluetongue and eastern equine encephalitis for example, can climb or fall dramatically with fluctuations in temperature and precipitation (Sellers 1980; Jiménez Clavero 2012; Pioz *et al.* 2012), as can vector-borne human diseases, such as bubonic plague, dengue and malaria (Gublner 2009; Ben Ari *et al.* 2011; Thomson 2014). Outbreaks of these pathogens are often seasonal and environmentally sensitive. Though typically endemic/enzootic, in the right conditions they can take on epidemic/epizootic proportions. Anomalous climate can create opportunities for vector populations to expand in number and range, as well as extend the pathogen's annual window of activity. Morbidity and mortality associated with these pathogens also climb dramatically, when susceptible, naïve populations move into endemic/enzootic zones. The 791 equine epizootic is thought to illustrate such an event. Then eastern equine encephalitis possibly broke out in Charlemagne's warhorses as they passed along the marshy banks of the middle Danube (Gillmor 2005; Lubelczyk *et al.* 2013 assess a more recent EEE outbreak). Without palaeomicrobiological evidence for pathogens causing early medieval animal disease, however, synergy between soil- or vector-borne animal pathogens and climate is elusive.

2. Early medieval animal mortality events

Searches for evidence of animal disease in heterogeneous early medieval sources – annals, capitularies, chronicles, correspondence, hagiography, history, poetry – have turned up 87 references to epizootics and zoonotic disease outbreaks in livestock and humans (Newfield 2013a, pp. 80-84; Newfield 2015, pp. 6-7). The majority of the passages date to the 8th (16), 9th (28) and 10th (28) centuries. There are only four 5th-century references, nine 6th -century references, and two



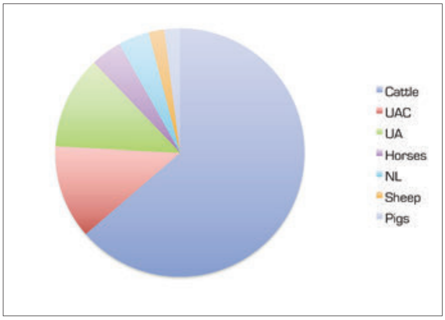


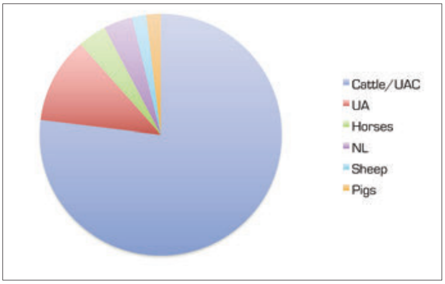
Fig. 1 (left). Passages per century.
Fig. 2 (right). Non-human species referenced in 87 collected passages (UAC = unidentified *animalia* clearly cattle; UA = unidentified *animalia*; NL = non-livestock).

7th-century references (fig. 1). Whether there were more animal and human-farm animal plagues in the Carolingian period (750-950) than earlier, as the sources suggest, is uncertain. The higher rates of source composition and survival characteristic of Carolingian Europe may account for the notable increase in epizootic and zoonotic human-domesticate disease after 750.

The 87 passages contain no fewer than 63 references to cattle, 24 references to "animals", 4 references to horses, and 2 references each to sheep and pigs (fig. 2). There are 3 reports of dead and diseased wild animals (deer (591), birds (671) and bees (993)), a single report of a canine epizootic (776), and several references to simultaneous pestilential deaths in multiple non-human species: cattle and deer (591); cattle and horses (725-26); cattle and sheep (887); cattle and birds (917); cattle and bees (993); cattle, pigs and sheep (994); and cattle and pigs (996). There are 29 references to zoonotic plagues affecting humans and domesticated species, 20 of which were plagues of humans and cattle, and nine of which afflicted humans and "animals". Cattle account for 66% of the references to diseased domesticates. Moreover, no fewer than 13 of the 24 ambiguous references to dead *animalia* were unquestionably bovines, meaning that cattle in fact account for 80% of the references to domesticates[5] (fig. 3). Of the 29 passages pertaining to zoonotic human-domesticate plagues, at least 25 targeted people and cows[6] (fig. 4).

[5] Multiple passages survive for several large plagues, like those of 809-10, c.820, 868-70, 939-43 and 986-988. Most explicitly refer to cattle. Some, however, refer vaguely to "animals". These *animalia* were surely bovines.

[6] The remaining four passages were plagues of humans and unidentifiable "animals". This reckoning differs from that presented in Newfield 2013a as the 569-570 and 986-988 plagues are now understood to have been zoonotic.



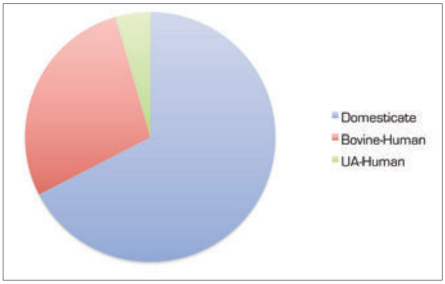


Fig. 3 (left). Non-human species referenced in 87 collected passages, UAC grouped with Cattle.
Fig. 4 (right). Non-zoonotic epizootic disease, bovine-human disease and unidentified *animalia* (UA)-human disease.

The bulk of the passages, 51 of them, refer to a mere 8 major inter-regional cattle plagues (in 569-570, 583-584, 699-701/708, 809-810, c.820, 868-870, 939-942, and 986-988). These large events ranged in scale and severity, and in all likelihood the dates affixed to them misrepresent their actual chronologies. The 986-988 outbreak, for instance, is visible in England, Wales, Ireland and possibly Scotland, yet the pathogen was almost certainly ecdemic to northwestern insular Europe. Likewise, the 583-584 bovine deaths are traceable in central and northern France, but the causative microorganism likely spread westward or northward into these regions. These 8 plagues represent the minimum occurrence of large transboundary animal disease outbreaks in the early postclassical era. Sources are scant for several European regions throughout the period and thin in general for many quarter and half centuries. Several of the seemingly minor disease outbreaks – the *gravis morbus* that Gregory of Tours has irrupting in cattle and deer in 591, "the great murrain of cows" documented in Ireland in 777-779, or the *boum pestilentia* of 878 read in the *Annales fuldenses* (Newfield 2013a) – may have been as prevalent, long-lasting and severe as the plagues identified above.

Bovines suffered in all of the clearly major pestilences. On at least three occasions people suffered too (in 569-570, 868-870, 986-988, and possibly 809-810 and c.820). For medical and veterinary historians this is problematic. No pathogen is known to modern science that is capable of causing significant widespread mortality in both bovines and humans. Plagues affecting cattle alone may be tentatively identified as rinderpest or contagious bovine pleuropneumonia. Were the foot-and-mouth disease virus more lethal in the distant past than it is now (it kills less than 5% of its victims) it too may have been responsible for some large cattle die-offs, though its ability to cause disease in sheep and pigs, domesticates rarely encountered as diseased or dead in early medieval sources, would have to be accounted for (Geering, Lubroth 2002, pp. 1, 7, 10-15). When diarrhea or gastrointestinal symptoms are reported, a rinderpest identification of a cattle plague acquires stronger footing as loose bowels are a unique and classic expression of the virus[7].

Scholars have attributed large zoonotic disease outbreaks to contemporary observers erroneously conflating concurrent disease mortality in people and cows. To quote one veterinary historian, "there was a tendency", in the distant past, "to observe a 'simultaneity' of epidemics in man and animals… and to attribute the same cause to them… now we know that such epidemics… had different causes…" (Mantovani 2001, p. 41). Localised disease mortality simultaneous in humans and other animals may be tentatively assigned to anthrax, though that virulent soil-borne pathogen typically occurs in special climatic contexts (droughts preceded by heavy rain and flooding) and most commonly afflicts grazing animals, cattle and sheep (Gates *et al.* 2001, p. 407). *Bacillus anthracis* may lie behind the seemingly circumscribed 591 bovine-cervine mortality or the 887 bovine-ovine pestilence, but it cannot account for large plagues (Spinage 2003, p. 85; Newfield 2013a, pp. 91-92). Recent studies of the evolution of morbilliviruses present a possible solution. Molecular clocks carried out on the phylogenetically similar measles and rinderpest independently testify that these viruses diverged postclassically (Furuse *et al.* 2010; Wertheim, Kosakovsky Pond 2011; on molecular clocks: Lemey, Posada 2009, pp. 362-372). In other words, a rinderpest lineage colonised human populations and became measles not several millennia ago as was long thought (c.3000 BCE was often put forward: Barrett, Rossiter 1999, pp. 93-94; Barrett 1999, pp. 1559, 1563-1564; Griffin 2001, p. 1401; Roeder, Taylor 2002, p. 516; Cliff *et al.* 2004, pp. 42-43 (with maps); Roeder *et al.* 2013), but in the Early Middle Ages (c.1000 CE). Prior to this divergence, a RPV predecessor, likely endemic/enzootic in Asia, circulated in bovines and, it has been proposed, periodically jumped to and spread within human populations until it burnt itself out (Banyard *et al.* 2006, p. 23; Furuse *et al.* 2010, p. 3; Newfield 2015). The ancestral morbillivirus may account for large zoonotic human-bovine plagues in Europe in the pre-divergence period.

[7] Anderson *et al.* 1996, p. 9; Wohlsein, Saliki 2006, pp. 70-71. Bovine Viral Diarrhea Virus is fairly contagious but not especially lethal with a 4-8% mortality rate. Its victims suffer diarrhea, but the virus is considered new (emerging in the 1940s) and it does "not behave like rinderpest" (Deregt 2005).

Postclassical climatic anomalies and extreme weather also killed domesticates. Three of the 87 plague passages assessed herein may in fact concern climate- or weather-related animal deaths. For instance, the 916-917 "mortality of cattle and birds" documented in the *Annals of Inisfallen* is assigned no specific cause, but the *Annals of Ulster* and *Chronicon Scotorum* attribute these deaths to frost, cold and "great snow". In 962, the latter text reports "cattle suffered a great plague, with snow and diseases" (Newfield 2013a, p. 83). Several other passages explicitly intertwine anomalous climates, extreme weather and pathogens with livestock health. There is Nithard's account (not included in the foregoing analysis) of an "excessively cold and long" 842-843 winter that was "full of diseases" and "harmful to cattle" (Newfield 2013a, pp. 83-84), and an early entry in the *Annales xantenses* (4) that associates uniquely the 809-810 panzootic with a *hiemps valde dura*. The *Annales regni francorum* (154), *Annales fuldenses* (22) and Astronomer (*Vita*, XXXVII, 420, 422) align the c.820 pestilence with continual heavy rains and humidity, the three passages pertaining to the 860 *mortalitas animalium* affix it to a *hiems magna* (*Annales alamannicorum continuatio sangallensis prima*, 50; *Annales weingartenses*, 66; *Annales sangallenses*, 76), the *Annales fuldenses* (105) has the 887 bovine-ovine die-off occurring within the context of a hard winter, and many of the sources for the 939-42 cow plague have it occurring in the context of the *asperrima hiemps* (*Annales colonienses*, 98; Widukind of Corvey, *Res gestae saxonicae*, XXVI, 89, XXXII, 93-94; *Cronicon suevicum universale*, 67; Hermann of Reichenau, *Chronicon*, 113) and a period of flooding (Curschmann 1900, p. 106).

The majority of climate- and weather-related deaths, however, are explicitly reported as such. Some Carolingian annalists were unusually fond of documenting cows suffering electrical charges (lightning strikes) in fields (for example *Annales regni francorum*, 163-164; *Annales fuldenses*, 76-77). More than a cow or two may have indeed suffered electrocution on occasion: lightning strikes can kill multiple bovines sheltering beneath a single tree in a storm. One-off strikes claimed 45 cows in Darby, Pennsylvania, USA in July 2014 (Backus *Missoulian*), 55 cows in Río Bueno, Los Rios, Chile, in April 2014 (Anonymous *Diario el ranco*), and 18 cattle in Yellow Creek, Saskatchewan, Canada in July 2013 (Anonymous *CBC news*). But most weather-related livestock deaths were tied to periods of severe cold, drought, or persistent heavy rain. So in 824, 874, 881 and 893 "extreme cold" and "longer than usual" winters, and in 839, 875, 886 and 919 "violent storms", "heavy rains" and "sudden flooding", killed many Frankish animals (*Annales regni francorum*, 164; Astronomer, *Vita*, 470, 472; *Annales bertiniani*, 18; *Annales fuldenses*, 81, 84, 96, 104, 123, 127; *Annales sancti germani minores*, 3). These sorts of deaths occurred elsewhere too. A hard winter claimed "horses, camels and other animals" in Thrace in 716/717 (Theophanes Confessor, *Chronicle*, 546), and Irish animals died in hard winters and "snow of unusual depth" in 747/748, 798/799 and, as noted, 916/917[8].

Animal losses from anomalous climate and extreme weather were likely marginal, relative to losses sustained in disease outbreaks. General flooding probably killed hundreds of domesticates on occasion and long, severe winters were undoubtedly lethal too, though domesticates may have suffered more from a dearth of fodder and pasture than low temperatures. These animals, like victims of disease, became feed for scavenging birds and dogs, were interred in individual pits, or possibly collected and buried in mass graves. The *Annales fuldenses* (92) reports in the context of the 878 cattle plague that diseased animals were dragged out of their stalls and abandoned in fields. The Poeta Saxo relates cows were "were lying dead" in fields after the 809-810 panzootic, though he was not a contemporary (*Annalium de gestis*, IV.236-253, 51-52). Whether contemporaries harvested meat or raw materials from them is unknown. Early medieval annals and histories are quiet on the consumption of unslaughtered animals. There were, of course, biblical restrictions on the eating of carrion (Leviticus 22:8, Exodus 22:31; Deuteronomy 14:21) and some early medieval penitentials forbade the eating of animals that died a natural death (Meens 1995), suggesting carrion was consumed. The *Capitulare de villis* implies diseased animals were eaten, though perhaps not by the elite, but no references to the consumption of "plague cattle" in early medieval sources are known (for the high medieval period: Newfield 2012b, pp. 619-639). The available zooarchaeology indicates that animals that died in early medieval mortality events were not always considered edible (cf. Putelat 2013, p. 266).

Zooarchaeological evidence for mass animal burials possibly evidencing epizootics, or climate- or weather-associated mortality events, is presently meager. Several sites have been identified but few have been analysed in depth (Binois 2013, pp. 277, 279-280, 285; Renou *et al.* 2013, pp. 133, 135; Putelat 2013, pp. 259-263 surveys known French sites evidencing extraordinary medieval animal mortality). Two large animal "plague pits" dating to the Early Middle Ages have been unearthed and studied, in Shapwick, Somerset, England, and Luxé, Charente, France (Gidney 2012, pp. 240-245; Gidney forthcoming; Renou *et al.* 2013). The first has been carbon-14 dated to 980-1160 and the latter

[8] *Annals of Ulster*, 211, 281, 433. The *AU* dates the first and second of these events to 747 and 798. They appear a year later in the so-called *Chronicle of Ireland* (219, 260).

Fig. 5. Luxé bovine 1555 (photo: Dr. Sylvain Renou).

to the early 7th century, though some ^{14}C dates from the Luxé bones extend as far back as 570. Seven articulated adult male bovines, likely draft animals, were uncovered in a single, partially excavated mass grave at Shapwick. They evidenced no skeletal stigmata and were buried simultaneously in a former limekiln with lime (a traditional agricultural disinfectant), indicating that they were healthy, died a sudden death, and succumbed to disease. Ten largely articulated bovines were discovered in closely situated singular pits at Luxé (figs. 5-6). They were mostly between one and six years of age, deposited deeply and quickly, and displayed no skeletal evidence for malnutrition or chronic infection. There was no or little evidence for the salvaging of meat or raw materials at Shapwick or Luxé.

The Luxé bovines possibly died in the 569-570 plague and Shapwick bovines in the 986-88 plague, but other epizootics occurred near these sites that also match the rough dates affixed to them, the aforementioned 583-584 and 591 epizootics and the 1041 and 1048 cattle pestilences recorded in the *Anglo-Saxon Chronicle* (163, 167). While there are several indicators that the Shapwick and Luxé animals died of disease, climatic anomalies, extreme weather and food scarcity cannot be ruled out. Laboratory identification of causative pathogens is needed before these English, French or Swiss burials are considered definitive evidence for epizootic disease.

Fig. 6 Luxé bovine 1576 (photo: Dr. Sylvain Renou).

Smaller mass graves have been uncovered in Bure, Jura, Switzerland (five bovines), and in nearby Bourogne, Franche-Comté, and Vellechevreux, Franche-Comté, France (three and four bovines respectively) (Putelat 2013, pp. 250-258). Most of these animals (11 of 12) were more than a year old and all appear to have been healthy (showing no signs of chronic disease or malnutrition). Some of the Swiss animals were flayed and dehorned (postmortem). It has been proposed these three graves evidence a regional mortality event, possibly an epizootic considering some of the Bure animals were buried with limestone, at the end of the Early Middle Ages.

3. Animal plague triggers

Evidence for large early medieval animal mortalities is growing. The triggers, origins, temporal and spatial extent, pathogenic causes, and consequences of these disease-, climate- and weather-associated large animal die-offs, however, are poorly understood. Significant short- and weaker long-term consequences have been expected of large bovine mortalities in the Middle Ages and attempts have been made to trace the chronologies and trajectories of several medieval animal plagues (Gillmor

2005; Newfield 2009, 2012a; Slavin 2010, 2012; Campbell 2010a, pp. 288-291; DeWitte, Slavin 2013). It has also been suggested vast, interregional cow die-offs, the 1314-1325 panzootic in particular, were associated to climate. Campbell's synthesis of the available palaeoclimatology demonstrates beyond doubt that the 14th-century bovine pestilence, which claimed a million plus head when it passed through England c.1319-1321, occurred in the midst of "a sharply defined and distinctive" climatic anomaly (Campbell 2010a, p. 293; Campbell 2010b, pp. 14, 20-24, 31-32; Campbell 2011, pp. 184-197; Jordan 1996, p. 35). This anomalous climate is proposed to have triggered the event and possibly augmented the virulence of the causative pathogen.

An assessment of the triggers for early medieval epizootics found that neither climatic anomalies, food shortages, human migrations nor wars routinely coincided with animal disease events and therefore that these were not quintessential triggers of transboundary livestock plagues (Newfield 2013a, pp. 98-113). There are, of course, exceptions. The arrival of the Lombards in Italy in 568 with their possessions from western Hungary and their brief forays into France immediately thereafter (Gregory of Tours, *Libri historiarum X*, IV.41, 174; Paul the Deacon, *Historia langobardorum*, II.7-9, 76-77) correlate well with the 569-570 human-bovine pestilence reported to have spread through much of *Italiam Galliamque* (Marius of Avenches, *Chronica*, 238; Newfield 2013a, pp. 98-99, 111). Knowledge of early medieval climatic anomalies, food shortages, human migrations and wars is also partial, meaning triggers may have occurred that are unknown or poorly understood now. As large bovine plagues in all probability originated in disease pools to the east or south, more attention is required of extra-European evidence. A survey of Western Asian texts for livestock disease in the early postclassical period in particular may better illuminate the origins and triggering events of major plagues reported in European sources.

Still, some strong associations emerge from the known evidence. Several cattle plagues were clearly associated with anomalous climates that triggered poor harvests and food shortages. In fact multiple major and seemingly minor disease outbreaks coincide well with year-long or multi-year periods of food availability decline generated by short-term climatic shocks. The major plagues of c.820, 868-870, 939-942, and the seemingly lesser events of 445, 447, 551/552, 591 and 699-701/708, for instance, match up with food shortages. Countless subsistence crises occurred, however, for which there is no evidence for animal disease (at least 18 in the Carolingian period: Newfield 2013a, p. 107) and both major and minor plagues took place in lieu of food shortages, notably the 809-810 panzootic, but it is perhaps no coincidence that large plagues occurred often in the midst of genuine famines. Ten of the 22 food shortages reported in the Carolingian period have been identified as particularly long-lasting, general and severe. These ten famines were generated undoubtedly by anomalous climate (multi-year periods exceptionally cold, dry and/or wet) and three of these ten famines were contemporary to widespread acute bovine disease (food shortages and anomalous climates 750-950 CE: McCormick *et al.* 2007; Newfield 2013b). Put another way, 75 per cent of major Carolingian-era cattle plagues occurred during major, climate-triggered famines. The implication is that large food shortages worked in synergy with epizootic diseases, facilitating their circulation. That seemingly minor Carolingian-era animal mortalities do not coincide with major food shortages underscores this connection. The association would gain more currency if large bovine plagues were spread directly intraspecies, which they almost certainly were. The specifics are blurry but it is possible that the regional and interregional movements of people and their animals that shortages fostered put plagues in motion.

Climatic anomalies and food shortages may have also contributed to epizootic mortality through the medium of malnutrition. In many anomalous climates domesticates may have suffered from a prolonged dearth of fodder and pasture. When harvests failed human-domesticate competition for food resources intensified, to the determinant often of livestock. That some modern plagues of cattle, notably rinderpest, can achieve a mortality rate of 95 to 100 per cent in epizootic zones regardless of the nutritional standing of their victims, however, suggests that major early medieval cattle pestilences may have killed whether or not cattle were well fed (Wohlsein 2006, p. 69; Newfield 2009, pp. 177-178, 181). The Shapwick and Luxé bovines may testify to this.

4. A case study: the anomalous climate, famine and epizootic c.940

Multiple sources record a bovine epizootic in late 930s and early 940s in areas of modern-day France and Germany. Widukind of Corvey and Flodoard of Rheims, two mid 10th-century historians, both document the plague. Like most early postclassical accounts of epizootic disease, Widukind's report is short. In his *Res gestae saxonicae* (XXXII, 93-94), put to parchment no earlier than 962, the monk working in what is now eastern North-Rhine-Westphalia, writes simply of a *boum pestilentia* in 941. The Champagne-based Flodoard provides a lengthier passage. In his *Annales* (389), likely composed on a year-by-year basis, he writes of the *mortalitas maxima boum* in 942. Flodoard emphasises that the mortality was so thorough *ut pauca huiusmodi animalia in his remanserint terris*.

Widukind and Flodoard's passages are corroborated by other accounts, some of which are interdependent. The *Annales colonienses*, a thin and noncontinuous collection of annals running from 776 to 1028 possibly kept at Cologne in the mid 900s, records a *mortalitas animalium* in 939 (98). In this it is unique. All other accounts of the plague affix it to 940-942. As the *Annales colonienses* correctly dates the 941 death of Münster's bishop Rumoldus but assigns the 936 death of Henry I to 935 (these events immediately follow and precede the animal mortality), it is possible its account of the plague should be redated to 940. The *Chronicon suevicum universale*, likely composed at Reichenau and completed c.1045, documents a *mortalitas animalium* in 940 (67), the same year Hermann of Reichenau reports a *pestis animalium* in his *Chronicon* (113), finished in the year of his death (1054). This year was adhered to by later texts, such as the 13th-century *Annales capituli cracoviensis*, which drew on earlier sources and then documents a *mortalitas iumentorum* (15). Like Widukind, the *Annales sangallenses maiores*, which is associated with the monastery of St. Gall and seems to be independent from other texts from 918, has a *mortalitas boum* occurring in 941 (78)[9]. Like Flodoard, Adalbert of Magdeburg, the archbishop on the Elbe, references an *immensa mortalitas boum* in 942 in his continuation of Regino of Prüm's *Chronicon* (16), completed in 967 or 968, though he is almost certainly a year late as he reports the die-off as occurring in tandem with the comet reported in 941 by Widukind and others[10].

Only Flodoard provides spatial parameters. As far as he was concerned, the plague affected cattle in *Francia* and *Burgundia*. But its occurrence was not restricted to these regions, which correspond roughly to modern-day central and northeastern France, Belgium, the Netherlands and western Switzerland. The *Annales colonienses* and *Annales sangallenses maiores* possibly refer to dead cows in western

9 An epigram encountered in Melchior Röchell's 16th-century work on Münster's bishops may also refer to the 941 cattle plague. Following mention of a food shortage and the 941 comet, one encounters *fera prosternit corpora multa lues* ("a plague overcame many bestial bodies"?): *Zusätze Röchell's zu frühern chronisten*, 187-188.

10 So too the later (written in the 1050s) *Annales einsidlenses*, 142. The 941 comet is reported in European, West Asian and East Asian sources. Although not free of errors (Widukind is here English) try Kronk 1999, pp. 152-155.

Germany and northern Switzerland, and Widukind and Adalbert to plague cattle in what is now central and eastern Germany. If Flodoard's date is correct, it would appear that the outbreak progressed westward through these regions. As the pathogen was unlikely soil- or arthropod-borne, but rather spread directly between susceptible animals, it was almost certainly ecdemic within the epizootic zone, and introduced from somewhere else. It is possible that this plague and the mid-10th-century cattle mortality reported by Constantinopolitan John Skylitzes, who drew extensively on earlier Greek histories in his *Synopsis historion* composed c.1100, were one and the same. Skylitzes has Byzantine cattle suffering an acute disease that "wastes and destroys bovines" (XII.8, 242-243) known then as *krabra* (κράβρα) in the reign of emperor Romanos II (959-963) but, by Skylitzes' reckoning, first affected animals in the region during the reign of Romanos I (919-944). He associates the plague's onset in Greek lands with Romanos I's construction of the palace of Bonos. When construction started on that palace is not known. The meaning of *krabra* is also obscure; it is not mentioned in the *Geoponika* (a mid 10th-century Byzantine anthology of late antique anthologies of earlier agricultural treatises which touches on livestock disease).

Skylitzes emphasises that the disease was widespread in Byzantium, as Flodoard emphasises its expansiveness in *Francia* and *Burgundia*. It is not implausible therefore that the plague they document is the same as that encountered in the year AH 326 (937/938) in 12th-century Baghdadi Ibn al-Jawzi's *al-Muntaẓam fī ta'rīkh al-umam wa l-mulūk* (XIII, 374), a historical work also based on earlier texts[11]. In the manner of Widukind and the Central European annalists, al-Jawzi keeps his account brief: "in this year there was a plague (*wabā'*) among cattle". He provides no indication of the pestilence's scope, though it afflicted presumably animals in the area of modern-day Iraq. Firm connections between Flodoard, Skylitzes and al-Jawzi's plagues are elusive, but it is possible a cattle pestilence irrupted into Western Asia c.937/938, spread westward through Byzantine lands c.939, and reached Central and Western Europe c.940-942. The disease victims that made their way into Flodoard and Widukind's histories may represent a small percentage of the causalities of a mid-10th-century confluence of Eurasian disease pools.

These bovine mortalities occurred in a particular environmental and socioeconomic context: a period of anomalous climate and famine. The

[11] Dr. Conor Kostick has kindly provided a translation of this passage (and others discussed below) from al-Jawzi's text which was made by Or Amir with funding from Dr. Kostick's Nottingham Advanced Research Fellowship.

Annales colonienses positions the animal mortality within the context of a *hiemps valida* in 939 (again possibly 940) and Widukind writes of the *asperrima hiemps* and *fames validissima* in 940, a year before the cattle plague. For the annalist of the *Annales sangallenses maiores*, 940 was also an *annus durus* deficient in grain (*deficiens fructus*). The *Chronicon suevicum universale*, Hermann of Reichenau and *Annales capituli cracoviensis* as well document a difficult winter in 940 alongside the animal die-off. Hermann specifies the hard winter preceded the epizootic. The interdependent *Annales laubienses* (16) and *Annales leodienses* (16), the common source of which was likely kept at Lobbes or Liège, report a subsistence crisis (*fames*) in 941. There is also evidence of a severe food shortage in the area of Münster in that year. A passage from Florenz von Wevelinghoven's 14th-century *Chronik der bischöfe von Münster* (12-13) based on non-extant sources about the *Münstersche* bishop Rumoldus refers to the *maxima fames* in conjunction with the 941 comet[12]. Flodoard reports a *fames magna* concurrent with the cattle mortality in 942 and two independent sources document a food shortage in 943, the *Annales iuvavenses* (*fames valida fuit late*) (743) and *Annales lobienses* (*fames*) (234), but this date is incorrect possibly in both instances. The second text, related to the *Annales laubienses* and *Annales leodienses*, has the shortage occurring alongside the 941 comet and the first text muddles the timing of several events around this time (it assigns the 943 Bavarian defeat of the Magyars to 942 and the 947 death of the Bavarian duke Berthold to 948; the *fames* is sandwiched between these occurrences). There are, however, indications that the subsistence crisis persisted beyond 942. Whether the demons Flodoard has destroying Parisian crops in 944 were part of long-standing shortage is uncertain (*Annales*, 391).

Flodoard has the *fames*, like the plague, affecting *Francia* and *Burgundia*. Florenz von Wevelinkhoven (*Chronik*, 12) presents the subsistence crisis, at least in the area of Münster, as universal. A claim of widespread food shortage is not, in the early 940s, unjustified (McCormick *et al.* 2007, pp. 888-889; Newfield 2013b, pp. 146-148). Severe food shortages and hard winters are reported far beyond Germany and France then. The *Annals of Ulster*, which were likely kept in the 940s in Northern Ireland possibly at Armagh (Evans 2010, pp. 28-30, 44), reports a great frost and the freezing of Irish lakes and rivers in 940 and 944 (461, 465), though does not mention failing harvests or a food shortage.

[12] Röchell's work on Münster's bishops also references a *horrenda fames* in association with the 941 comet (*Zusätze Röchell's zu frühern chronisten*, 187-188).

Liudprand of Cremona, the Lombardian historian, refers to a major subsistence crisis in Italy around this time in his *Antapodosis*, composed c.950 (V.2-4, 877-878). He references a *fames*, "which with its greatness sadly devastated Italy", after Ramiro II's defeat of Abd al-Rahman III at Simancas in 939 but before Hugh of Italy's appointment of Anscar of Spoleto, who died in 940, as Duke of Spoleto in 936. Yet Liudprand records the subsistence crisis alongside the appearance of a comet, likely the same comet reported in conjunction with a *fames* in transalpine texts in 941. The *Ta'rīkh jazīrat Şiqilliya* (also know as the *Cronica di Cambridge*), a short 10th- or 11th-century account of events in Muslim Sicily between 827 and 965, recounts a "great famine" in the region of al-Madīna (Palermo) in 940 and the spread of that famine across Sicily in 941 (XXVII, 288-289). To the east al-Jawzi documents severe Baghdad-area subsistence crises from 941 through 945. Neither Liudprand nor the author of the *Ta'rīkh jazīrat Şiqilliya* identify any cause of the Italian crises, but al-Jawzi mentions infrequent rain and excess human and bovine mortality (possibly still the plague) in 940, a locust infestation in 943, and heavy rains and a late winter in 944 (*al-Muntaẓam*, XIV, 7, XIV, 19, XIV, 27, XIV, 34, XIV, 47). Bar Hebraeus, a 13th-century Baghdadi historian who like al-Jawzi drew on earlier material, also documents mortal food shortages in Baghdad in 940 and 945. In connection to the 940 dearth, he relates flooding (contradicting al-Jawzi) and an epidemic (*Chronography*, 162, 164). Farther east, Chinese annals record three consecutive hard winters starting with the winter of 939/940 (Fei *et al.* 2003, pp. 214-225; Fei, Zhou 2006, pp. 447-451).

Of course, no text identifies a single overarching forcing mechanism behind these food shortages, but the concurrence of crises in disparate regions suggests one. This is not to say that food entitlement decline, to use Sen's language (Sen 1981; Sen and medieval food shortages: Franklyn-Lyons 2013), did not play an important role in these events; al-Jawzi and Bar Hebraeus' references to soaring foodstuff prices evidence that it did. While entitlement decline exacerbated shortage-associated penury and mortality c.940, there is no evidence it triggered it. Natural archives of past climate, however, illuminate an anomalous environmental context that was probably the underlying cause, meaning poor harvests, or food availability decline, generated shortage conditions.

Two large, stratosphere-clouding volcanic eruptions took place c.940. Implicated are Eldgjá in southern Iceland and Tianchi (otherwise known as Baitoushan, Changbaishan or Paektu) on the North Korean-Chinese border. Exceptional cold and famine conditions in Europe and Asia at this time were linked with Eldgjá in the 1990s (Zielinski *et al.*

1995; Stothers 1998; Fei, Zhou 2006; McCormick *et al.* 2007, pp. 888-889; Ludlow *et al.* 2013). Tianchi's so-called Millennium eruption has been overlooked, presumably on account of its shifting date, though it, like the Eldgjá event (Zielinski *et al.* 1995; Thordarson *et al.* 2001), is thought to have loaded the stratosphere with enough material to cool Northern Hemispheric climate subdecadally (Horn, Schmincke 2000; Zou *et al.* 2010; Yin *et al.* 2012).

Volcanic eruptions can have a pronounced if short-lived effect on climate (Kelly, Sear 1984; Bradley 1988; Robock 2000; Schmincke 2004; Cole-Dai 2010). Volcanic ash from large explosive events falls from the atmosphere within two weeks, but sulphur dioxide (SO_2) injected into the stratosphere and there converted to sulphuric acid (H_2SO_4) can circulate as fine sulphuric acid aerosols (H_2SO_4/H_2O) for multiple years before its deposition as sulphate (SO_4^{2-}). These aerosols veil the sun, absorb and backscatter solar radiation, and thereby cool the troposphere and lower surface temperature. Yet the impact of volcanic eruptions on climate is complex. Large events, including possibly the massive c.1258 eruption (Timmreck *et al.* 2009), do not necessarily lower global temperature. They also affect both temperature and precipitation, and they do so variability over space. Tropical eruptions can lead to winter warming in Europe (Robock 2000, pp. 205-209; Fischer *et al.* 2007) or cold, wet years (Wegmann *et al.* 2014; Luterbacher, Pfister 2015), though large events generally decrease rainfall (Iles 2013; Iles, Hegerl 2014) and can cause drought (Joseph, Zeng 2011; Haywood *et al.* 2013; Zhou *et al.* 2014). Concentrations of volcanic SO_4^{2-} from major eruptions are detected in polar and glacier ice (Hammer *et al.* 1980; Gao *et al.* 2008) and sudden, short-term temperature drops, associated with thick volcanic clouding, register as narrow rings or frost rings in mature trees (LeMarche, Hirschboeck 1984; Scuderi 1990; Salzer, Hughes 2007; D'Arrigo *et al.* 2013).

As with most undocumented or palaeo eruptions, the dates of these Eldgjá and Tianchi events have shifted over the years according to the sources and methods scholars have employed to study them. The Eldgjá event was originally dated via tephrochronology to the early 10th century (Larsen 1979). Acid horizons in Greenlandic and Arctic Canadian ice cores have subsequently fixed it to the 930s (Hammer *et al.* 1980, pp. 231-233; Johnsen *et al.* 1992, p. 312; Zielinski *et al.* 1995, pp. 129, 132; Vinther *et al.* 2006; Thordarson, Larsen 2007). Two dates are favoured, c.934 and c.938. Glass shards ejected in the eruption and uncovered in the GISP2 archive were shown to match chemically glass from the event site, ensuring Eldgjá erupted in the 930s (Zielinski *et al.*

1995, pp. 134-135). Many dates of varying precision have been affixed to Tianchi's so-called millennium eruption, for example 860±100, 938-939, 946±10, 1039±18 and 05/1199-06/1200[13]. Even high-precision wiggle-match radiocarbon dating of extant tree trunks carbonised in the event has produced incongruent dates, perhaps owing to the pre-eruption emission of tree-killing gases (Yatsuzuka *et al.* 2010, pp. 933, 939). The current consensus is that the explosive plinian event, credited with the formation of Heaven Lake, occurred c.940. Recently volcanic glass deposited in the GRIP and NEEM S1 Greenlandic ice cores dated to 940-941±1 was associated chemically with the Millennium eruption site (Sun *et al.* 2014). It was then proposed, however, that the pre-Eldgjá chronologies of these ice cores were roughly six years late (Baillie, McAneney 2015, p. 112), meaning, should the newly proposed chronology be correct, that Tianchi erupted c.945.

That the epizootic, famine and eruptions more-or-less overlap suggests that they interacted or were somehow related. Causal relationships are difficult to establish, however, as the datasets used to flesh out these events are not easily married and much about the plague, shortage and eruptions remains unclear. The gaps in knowledge are striking. Neither the Eldgjá nor the Tianchi eruption has a firmly fixed date. The duration of these events is also not known, as is the duration, distribution and density of their dust clouds. The sighting in Asia and Europe of a comet in 941 (see above) suggests that volcanoes did not then densely fog the atmosphere. Widukind refers to a prolonged reduction in sunlight before the 936 death of Henry I (*Res gestae saxonicae*, XXXII, 93-94), which Stothers (1998, pp. 718-720; 2002) dated to 934 and interpreted as an Eldgjá dust veil. The exceptional cold, infrequent rain and food shortage conditions reported in 940 and 941 from Ireland to Iraq to China suggest Eldgjá and/or Tianchi erupted in 939. Subsequent environmental shocks, notably a locust infestation reported in Western Asia, Eastern Asia and Central Europe (al-Jawzi *al-Muntaẓam*, XIV, 27; Fei, Zhou 2015; Röchell, *Zusätze Röchell's zu frühern chronisten*, 187-188), and food entitlement decline may account for the persistence of subsistence crisis conditions in some regions beyond 941.

The available dendroclimatological data does not evidence vast stratosphere-clouding eruptions in 939, however. Trees are unable of assigning either the Eldgjá or the Tianchi eruption to a particular year. Extreme

13 A sample of the literature on the date of this eruption: Dunlap 1996; Liu *et al.* 1998; Hayakawa, Koyama 1998; Cui *et al.* 2000; Horn, Schmincke 2000; Zhengfu *et al.* 2002; Jwa *et al.* 2003; Wei *et al.* 2003; Taniguchi 2004; Wei *et al.* 2007; Yatsuzuka *et al.* 2010; Okuno *et al.* 2010; Wei *et al.* 2013.

poor growth years are visible, though, in many Northern Hemispheric dendrochronologies c.940. Tree-ring series as far apart as Solongotyn Davaa, Mongolia (D'Arrigo *et al.* 2001, p. 243), the French Alps (Corona *et al.* 2010, p. 361), Taymir, Siberia (Naurzbaev *et al.* 2002, p. 734; D'Arrigo *et al.* 2003, p. 258), Sierra Nevada, USA (Scuderi 1993, pp. 1434-1435), and Scandinavia (Helama, Lindholm 2003, pp. 171, 177; Helama *et al.* 2013; Kirchhefer 2004) appear to show one or multiple difficult years in the late 930s and early 940s, as does a composite British-Irish-German dendrochronology (Zielinski *et al.* 1995, p. 137). The dendro data revel that exceptionable cold was not limited to the regions in which it was reported c.940, but a consistent signal is not seen across the chronologies (as Zielinski *et al.* 1995, pp. 136-137 emphasised; for instance, a Solongotyn Davaa series has frost rings at 938, a Taymir chronology identifies 940 as a poor growth year, and a Finlish series detects severe drought in 939, 943 and 944), contrary to other major volcanic events of the pre-instrumental period, the 536-545 climatic downturn for example (Baillie 1994; Larsen *et al.* 2008). This inconsistency complicates any attempt to employ tree data to support the idea that one or more large explosive events were to blame for food shortages c.940. The "missing ring" hypothesis – that some trees may not produce an annual growth ring under skies loaded heavily with aerosols from large volcanic events – may be of significance here. Discussion of medieval eruptions in connection to this contested idea has been limited hitherto to the c.1258 event (Mann *et al.* 2012, Anchukaitis *et al.* 2012; Rutherford, Mann 2014; D'Arrigo *et al.* 2013), one of the largest eruptions of the last several millennia (Oppenheimer 2003; Lavigne *et al.* 2013). This 13th-century event, which left a sulphate horizon in polar ice (Greenlandic and Antarctic) far greater than the c.940 eruptions, failed to register a consistent signature in trees (cf. D'Arrigo *et al.* 2001, pp. 243-244).

The Eldgjá event is thought to have been long-lasting. Three years of significant Eldgjá-related stratospheric clouding is considered "realistic" on the basis of the acid signals in Greenlandic ice cores (Hammer 1984; Zielinski *et al.* 1995, p. 137), but the GISP2 data indicates that the dust veil persisted possibly for six years (Zielinski *et al.* 1995), and NASA scientist Stothers, marrying ice cores and texts (written evidence for unusual atmospheric phenomena, exceptionally cold winters, food shortages), argued the eruption, which he dated to the summer of 934, produced a stratospheric cloud that lingered for upwards of seven years (Stothers 1998; Fei, Zhou 2006, 2015). Detailed study of Eldgjá's tephra stratigraphy as well suggests the eruption spanned six to eight years and was marked by "explosive episodes" c.934 and c.939 (Thordarson *et al.* 2001, p. 51). That Eldgjá's eruption persisted for multiple years and was marked by explosive episodes may explain the unevenness of the climate signal registered in trees; that and the mixing in possibly of Tianchi's atmospheric loading. Naturally the veils generated by explosive Eldgjá episodes and the Millennium eruption would have differed. Both eruptions are typically assigned high ratings on the eight-point Volcanic Explosivity Index (see Gudmundsson *et al.* 2008 for a VEI 5 Eldgjá event and Yin *et al.* 2012 for a VEI 7 Tianchi event) and are thought to have produced dense, long-lasting stratospheric veils. But the VEI is an imprecise tool for understanding eruptions for which no definitive measurements of the mass, volume, height and distribution of the material ejected in the eruption exist (Newhall, Self 1982; Houghton *et al.* 2013). Two recent studies have downplayed Tianchi's affect on global climate. Xu *et al.* (2013) fix the Millennium eruption to 946±3 via wiggle-match dating of the trunk of a tree carbonised in the eruption but find no sulphate spike in the GISP2 ice core to associate it with and Sun *et al.* (2014) assign the event to 940-941±1 via a SO_4^{2-} signal considered too insignificant to have caused anomalous climate in Europe c.940. The absence of a consistent dendro signal for the Tianchi or the Eldgjá eruption may support this conclusion.

That only partial contours of the famine and epizootic are known poses another significant challenge for untangling the relationship between them, the eruptions and the dendroclimatological data. How exactly subsistence crises generated conditions conducive to the introduction and dissemination of ecdemic epizootic disease in Europe c.940 also remains to be established. Presumably exceptional regional and interregional movements of people and their animals in response to food availability and food entitlement decline facilitated pathogen dissemination. Although early postclassical reports of migration in the wake of dearth are few (for example *Annales fuldenses*, 40-41; Smaragdus, *Vita benedicti*, 204; Skylitzes, *Synopsis*, 105) and there is no evidence for the flooding of markets with domesticates during crises, 400-1000, both migration and the sale of movable property are common strategies of "disaster relief" during famines (Ó Gráda 2009, pp. 78-89) and both were likely employed postclassically to counter the effects of food shortage.

It remains possible that an explosive Eldgjá event or the Millennium eruption triggered the European and West Asian shortages of c.940, facilitating the introduction and diffusion of the epizootic disease in Europe, and possibly Western Asia. Many questions, however, remain. Did the cattle plague's arrival in Western Asia predate the onset in the region of the major subsistence crisis of c.940? Was its coming to Western Asia related to the seemingly smaller shortage of AH 324 (935/36 CE) in the area of modern-day Iran (al-Jawzi *al-Muntaẓam*, XIII, 357) or the years of exceptional cold registered in East Asian texts in the mid 930s (Fei, Zhou 2006)? Did food shortage conditions help diffuse the pestilence solely in Byzantium and Europe? Should warfare be considered as a factor in the pathogen's dissemination? Did movements of people and animals in association with Sayf al-Dawla's early campaigns into Byzantium (in 936 and 938) or Magyar activities in Central and Western Europe c.940 spread the disease?

5. Conclusion

Historians are now regularly working across disciplinary boundaries, uniting fragmented scholarship in an effort to produce more integrated and dynamic reconstructions of the past. It is via interdisciplinarity that our understanding of past non-human animal health and disease, both unexceptional and exceptional, and associations between animal die-offs and environmental and human factors, will improve. Certainly the welfare of the animals on which human societies depended cannot continue to be overlooked. Domesticates and their pathogens are integral components of the environmental and cultural history of past populations. The 87 plague passages and the bovine burials assessed herein may represent a foundation for investigations into domesticate health and disease in the early postclassical period that will hopefully include contributions from historians, zooarchaeologists, palaeoclimatologists and palaeomicrobiologists. There is much work to do. For text-oriented scholars, surveys of Arabic, Armenian, Greek and Syriac sources for animal disease, 400-1000, would identify new events and improve the chronologies and trajectories of large plagues already identified.

This paper has drawn attention to several large disease outbreaks among cattle. It has proposed that climatic anomalies through the medium of food shortage triggered and contributed to the diffusion of a few of these plagues. The ability of climate to trigger bovine epizootics in this way was explored in a case study of the mortality, famine and volcanic climate forcing c.940. Firm causal relationships between these events remain elusive, but the probability that they were linked is high. As major interregional disease outbreaks, like the c.940 cattle plague, were in all likelihood spread directly intraspecies, climate-generated food shortages contributed primarily by facilitating pathogen circulation. The effects of harvest failures and subsistence crises on human and animal movements in the early postclassical period require further attention, but it is most plausibly through the movement of live animals (and on occasion humans were zoonotic pathogens easily transmitted interspecies) that major famine-period animal plagues were diffused. This connection, though tentative, is indicative of the linkages that existed between humans, domesticates and the greater natural world in the past. People, their livestock and the environment were deeply intertwined and by teasing out connections we begin to understand the rich complexity of the past world we seek to understand.

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