Climate, disease and society in late-medieval Ireland[1]

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Abstract

Palaeoclimatic data are used to track the significant changes in atmospheric circulation patterns and weather conditions that affected Ireland between 1000 and 1500 CE. How these climatic developments and associated shifts in the epidemiological environment were mapped onto Irish society is explored using a tree-ring chronology reflecting the retreat and advance of oak woodland. Years characterised by significant weather-related food scarcities are identified from the Gaelic and Anglo-Irish Annals in combination with the independent record of English chronicles, grain yields and prices. Between the thirteenth and the

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fifteenth centuries the experience of the two countries is shown to have diverged. It is suggested that in late-medieval Ireland scarcity heightened the resort to violence and from 1348 was often a proximate cause of plague outbreaks. In combination, scarcity, violence and plague helped entrap fifteenth-century society in a low-level equilibrium of sparse population, economic underdevelopment, scarcely disguised poverty and low resilience to natural hazards.

Introduction—climate change as a major but neglected grand theme of late-medieval Irish history

Ireland 'more than any other [country] suffers from storms of wind and rain': thus wrote Gerald of Wales in his *History and topography of Ireland*, based upon firsthand observations from his two extended Irish visits in 1183 and 1185.[2] It constitutes what is probably the first reasonably detailed extant account of Ireland's climate. As a Welshman he does not appear to have been unduly perturbed by these now well-known characteristics of the Irish weather, rather, he comments favourably on the generally temperate nature of the climate and absence of extremes of either summer heat or winter cold. He was struck by the fact that the grass remained green throughout the winter, so that haymaking and the winter housing of livestock were not practised, and noted that snow was seldom seen and rarely lasted long. In his experience, thunder and lightning were equally rare, partly because 'you will scarcely see even in summer three consecutive days of really fine weather'. Hence his stress upon the windiness of the Irish weather ('a north-west wind, along with the west wind to its south, prevails here, and is more frequent and violent than any other') combined with its cloudiness and 'plentiful supply of rain'. These natural attributes meant that the island was 'richer in pastures than in crops, and in grass than in grain', with obvious influences on the agrarian economy and the composition of diets. He also considered the air 'so healthy' that 'you will not find many sick men, except those that are actually at the point of death'. On his testimony, fevers, apart from the ague, were comparative strangers to Ireland, whose insularity partially shielded it from the germs which circulated more readily on the continent.[3]

These observations about the Irish weather at the end of the twelfth century accord with what palaeoclimatic reconstructions are revealing about the distinctive climatic conditions prevailing at that time when the atmospheric circulation patterns characteristic of the Medieval Climate Anomaly (formerly the Medieval Warm Period) were firmly in the ascendant. For Ireland that meant a dominant Atlantic airstream, especially in the winter when a characteristically steep pressure gradient between the Azores and Iceland ensured that the North Atlantic Oscillation (NAO) was typically strongly positive. When the NAO was in positive mode Irish winters were usually mild, windy and wet, while incursions of cold, dry Arctic or continental air masses were kept at bay. One recent

[2] Gerald of Wales, *The history and topography of Ireland*, trans. and intro. John O'Meara (Dundalk, 1951), 34–5, 53–4.

[3] J.M. Diamond, *Guns, germs and steel: a short history of everybody for the last 13,000 years* (London, 1997), 202-05, 357-8.

reconstruction suggests that these conditions prevailed in four out of five years during the second half of the twelfth century and were the established norm from 1183 to 1200, at the time when Gerald of Wales was in Ireland.[4] The comparative stability of the NAO at this time is consistent with the unusually settled state of the weather during this benign climatic interlude (as expressed in the low year-on-year variance of a range of climate proxies—Appendix 5) and which not even a notable northern hemisphere volcanic eruption in *c*.1182 was able to disturb.[5] At this time Atlantic storms were to be expected but not, as Gerald says, extremes of cold, heat or drought. In these respects, the findings of climate science broadly corroborate his qualitative account.[6]

Yet the climate would not remain so temperate, nor had it always been so, as Gerald, a learned man, could have discovered for himself by consulting the Gaelic Irish Annals (hereafter Annals) which, by the late-twelfth century, already spanned more than 600 years. Within living memory, in 1156, these recorded that Ireland had endured 'great snow and intense frost…so that the lakes and rivers of Ireland were frozen over' and 'most of the birds of Ireland perished' (*Annals of the Four Masters*).[7] Lightning strikes (either because they damaged ecclesiastical buildings or were interpreted as acts of God) were regularly reported in the Annals, as in 1135 when the *Chronicon Scotorum* reported: 'Lighting took the roof from the tower of Clonmacnoise and made a hole in the tower of Roscrea'.[8] A few years earlier, in 1129, the *Annals of Inisfallen* noted a hot summer and

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[4] Appendix 3; Pablo Ortega *et al*., 'A model-tested North Atlantic Oscillation reconstruction for the past millennium', *Nature* 523:7558 (2015), 71–4. Data: www.ncdc.noaa.gov/paleo/study/18935.

[5] Appendix 5.

[6] Gerald's retrospective account of the stormy winter of 1171–2 is also consistent with NAO reconstructions for those years: 'The storms raged so unceasingly and with such persistence that throughout that whole winter scarcely a single ship had succeeded in making the crossing to the island, and no one could get any news whatsoever from other lands': A.B. Scott and F.X. Martin (eds) *Expugnatio Hibernica: the conquest of Ireland by Giraldus Cambrensis* (Dublin, 1978), 103 (who, in corroboration of Gerald's account, cite the tempestuous seas preventing re-supply of Henry II's forces in Ireland. See p. 316 of Thomas Jones (ed.) *Brut y Tywysogyon, or the chronicle of the princes: red book of Hergest version* (Cardiff, 1955), and William Stubbs (ed.) *Radulfi de Diceto decani Lundoniensis opera historica*: *the historical works of Master Ralph de Diceto, dean of London* (London, 1876). The *Annals of Inisfallen* offer a less specific description of 'Very bad weather this year, which killed the better part of the cattle of Ireland' in 1172: Francis Ludlow, 'The utility of the Irish Annals as a source for the reconstruction of climate' (unpublished PhD thesis, Trinity College Dublin, 2010), vol. 2, 193. Hereafter all Gaelic annalistic texts are referred to by their common titles and their bibliographical details may be found under these at the Corpus of Electronic Texts (CELT) website, www.ucc.ie/celt; unless otherwise stated, references are to the original citations as given in Ludlow, 'Utility of the Irish Annals', vol. 2 (hereafter Ludlow, 'Utility 2').

[7] Ludlow, 'Utility 2', 190–1.

[8] Ludlow, 'Utility 2', 181.

drought so severe that 'the waters of Ireland dried up, and there was a great mortality of beasts and cattle'.[9] And the previous century, in 1095, 'a great sickness' was widely reported 'that killed many people, [lasting] from the first of August until the following May Day—i.e. the year of the mortality' (*Annals of Ulster*).[10] Evidently, Ireland was less immune to epidemics than Gerald supposed and once the Black Death arrived in 1348 plague mortality would weigh heavily upon Ireland's then-shrinking population.

In fact, as the Annals make clear, natural hazards—both physical and biological—posed a recurrent threat to Irish society throughout the late-medieval centuries, as the Irish climate was itself subject to change. Thus, in 1050, at the climax of the Oort Solar Minimum when very different patterns of atmospheric circulation prevailed, 'Much inclement weather happened in the land of Ireland, which carried away corn, milk, fruit, and fish, from the people, so that there grew up dishonesty among all, that no protection was extended to church or fortress, gossipred or mutual oath, until the clergy and laity of Munster assembled, with their chieftains, under Donnchadh, son of Brian, i.e. the son of the King of Ireland, at Cill-Dalua [Killaloe], where they enacted a law and a restraint upon every injustice, from small to great' (*Annals of the Four Masters*).[11] While this account has a clear subtext in the fraught politics of the high kingship of the period,[12] it also bears out the self-evident point that this economically under-developed society was heavily dependent for its subsistence upon the annual harvests of grain, grass, fruit and nuts, milk, meat, wool and hides. When production fell short poverty almost invariably increased and famine not unusually resulted. Scarcity, in turn, might prompt the needy to resort to crime

[9] Ludlow, 'Utility 2', 176.

[10] Ludlow, 'Utility 2', 161. For earlier lethal disease outbreaks reported in the Annals: W.P. MacArthur, 'Identification of some pestilences in the Irish Annals', *Irish Historical Studies* 6 (1949-50), 169-88; Ann Dooley, 'The plague and its consequences in Ireland', in L.K. Little (ed.), *Plague and the end of Antiquity: the pandemic of 541–750* (Cambridge, 2006), 215–30; Ciara Crawford, 'Disease and illness in medieval Ireland' (unpublished PhD thesis, National University of Ireland Maynooth, 2011); T.P. Newfield, 'Mysterious and mortiferous clouds: the climate cooling and disease burden of Late Antiquity', *Late Antique Archaeology* 12:1 (2016), 89–115; P.A. Grace, 'From *blefed* to *scamach*: pestilence in early medieval Ireland', *Proceedings of the Royal Irish Academy* 118C (2018), 67–93.

[11] Ludlow, 'Utility 2', 154. Tree-ring evidence suggests that the unspecific 'inclement weather' described in 1050 CE involved severe drought across much of north-west Europe, illustrating the benefits of combining documentary and natural proxy evidence: F. Ludlow and C. Travis, 'STEAM approaches to climate change, extreme weather and social-political conflict', in A. de la Garza and C. Travis (eds), *The STEAM revolution: transdisciplinary approaches to science, technology, engineering, arts, humanities and mathematics* (New York, 2019), 33–65.

[12] Lauren Baker *et al*., 'Mainstreaming morality: an examination of moral ecologies as a form of resistance', *Journal for the Study of Religion, Nature, and Culture* 11:1 (2017), 23–55.

and the powerful to violence.[13] Such circumstances were the breeding ground of disease, as in 1189 when the *Annals of Inisfallen* noted 'Great warfare and sickness and much bad weather this year'.[14] The weather was not, of course, the sole cause of violence and plague, rather it was the catalyst that often triggered and magnified them and to a degree shaped their courses.[15] As yet there has been little systematic investigation of these interactions,[16] which often weighed more heavily upon the poor than the privileged, partly because they have been eclipsed by the traditionally dominant historiographic grand themes of Church reform, the emergence of a high kingship, English invasion, conquest and colonisation, and the Gaelic revival.[17] Relevant palaeoclimatic information has also been wanting.[18] That has now changed and it is at last possible to place Gerald of Wales's description and the many environmental observations of the annalists in a proper scientific context.

Recent advances in palaeoclimatology have equipped historians with an array of high-resolution datasets constructed from a variety of natural and historical archives and now frequently spanning the entirety of the medieval

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[13] B.M.S. Campbell, 'Nature as historical protagonist: environment and society in pre-industrial England' (the 2008 Tawney Memorial Lecture), *Economic History Review* 63:2 (2010), 281–314: 291–6.

[14] Ludlow, 'Utility 2', 198.

[15] As in 1447 (*Annals of Ireland 1443 to 1468*): 'Great famine in the spring of this year throughout all Ireland, so that men were then wont to eat all manner of herbs for the most part. Great plague in summer, harvest, and winter, by which died the Prior of Ballyboggan and the Prior of Connell [Co. Kildare], and the Baron of Calatrym [Galtrim], and Gerott the sons [*sic*] of Walront, and the Listel, and many more in Meath, in Munster, in Leinster died of that plague, and it is difficult to get an account of the innumerable multitudes that died in Dublin by that plague': Ludlow, 'Utility 2', 275. For the association between plague outbreaks and spells of extreme weather in the bacterium's reservoir regions in inner Eurasia: B.M.S. Campbell, *The Great Transition: climate, disease and society in the late-medieval world* (Cambridge, 2016), 227–30, 246–52, 349–51; B.V. Schmid *et al.*, 'Climate-driven introduction of the Black Death and successive plague reintroductions into Europe', *Proceedings of the National Academy of Sciences* 112:10 (2015), 3020–5.

[16] A rare exception (but for the early-medieval period) is Donnchadh Ó Corráin, 'Ireland *c.*800: aspects of society', in D. Ó Cróinín (ed.), *A new history of Ireland, vol. 1, prehistoric and early Ireland* (Cambridge, 2005), 549–608.

[17] These themes are given pride of place in Art Cosgrove (ed.), *A new history of Ireland, vol. 2, medieval Ireland 1169–1534* (Oxford, 1987), and Brendan Smith (ed.), *The Cambridge history of Ireland*, *vol. 1, 600–1550* (Cambridge, 2018). Neither volume makes more than fleeting mention of the weather or pays serious attention to the frequency and severity of famine.

[18] Commenting in 1987, R.E. Glasscock ('Land and people, *c.*1300' in Cosgrove, *New history of Ireland, vol. 2*, 205–39: 206) observed that 'until there is more scientific study of this country's medieval climate we shall have to continue to pin our faith on Giraldus's random observations.' As noted above, however, the scientific evidence itself suggests Gerald's few remarks on the Irish climate might not be so random.

period.[19] These datasets have continued to clarify the geographical and temporal character of the often profound changes in climate that occurred over the course of the late-medieval centuries as temperatures and atmospheric circulation patterns transitioned from the relative warmth and stability of the Medieval Climate Anomaly to the cooler and more unsettled conditions of the Little Ice Age, with the critical tipping point from one global climate regime to the other occurring during the first half of the fourteenth century.[20] At the same time, a conjuncture of demographic, economic, commercial, political, military, religious and epidemiological developments was variously placing societies from Iceland to China under increasing stress.[21] Climate change thus emerges as an additional grand theme of late-medieval history and one of overarching global significance.[22] What ecological, epidemiological and societal relevance it may have had for late-medieval Ireland remains to be established.

Climate and society in late-medieval Ireland—the evidence

The evidence currently and potentially available to study climate change and extreme weather events across the first five centuries of the second millennium CE is better than that available to investigate interactions between climate and society.

From ice cores and tree rings, increasingly sophisticated reconstructions are available of two of the key drivers of global climate change, notably the varying output of solar irradiance and the scale, incidence and generalised location of sulphur-rich mega eruptions (Fig. 1). Successively, the years from

[19] Relevant datasets are hosted on the National Oceanic and Atmospheric Administration's (NOAA) Paleoclimate Data website: www.ncdc.noaa.gov/data-access/paleoclimatology-data. Recently a curated compilation of datasets has also been released by the PAGES2k Consortium, 'A global multiproxy database for temperature reconstructions of the Common Era', *Nature Scientific Data* 4(170088) (2017), doi:10.1038/sdata.2017.88.

[20] J.L. Brooke, *Climate change and the course of global history: a rough journey* (Cambridge, 2014), 350–444; Campbell, *Great Transition*, 1–19, 277–86.

[21] A.J. Dugmore, Christian Keller and T.H. McGovern, 'Norse Greenland settlement: reflections on climate change, trade, and the contrasting fates of human settlements in the North Atlantic islands', *Arctic Anthropology* 44:1 (2007), 12–36; R.D. Oram, and W. Paul Adderley, 'Lordship and environmental change in central highland Scotland, *c*.1300–*c*.1400', *Journal of the North Atlantic* 1 (2008), 74–84; Timothy Brook, *The troubled empire: China in the Yuan and Ming Dynasties* (Cambridge, MA, 2010), 50–78; Victor Lieberman, *Strange parallels: Southeast Asia in global context, c.800–1830, vol. 2, mainland mirrors: Europe, Japan, China, South Asia, and the Islands* (Cambridge, 2009), 1–112, 182–205; Tana Li, 'The Mongol Yuan Dynasty and the climate, 1260–1360', in Martin Bauch and Gerrit Jasper Schenk (eds), *The crisis of the 14th century: teleconnections between environmental and societal change?*, Das Mittelalter: Perspektiven mediävistischer Forschung, Beihefte 13 (Berlin and Boston, 2020), 153–68.

[22] Brooke, *Climate change and the course of global history*; Campbell, *Great Transition*; Lieberman, *Strange parallels*.

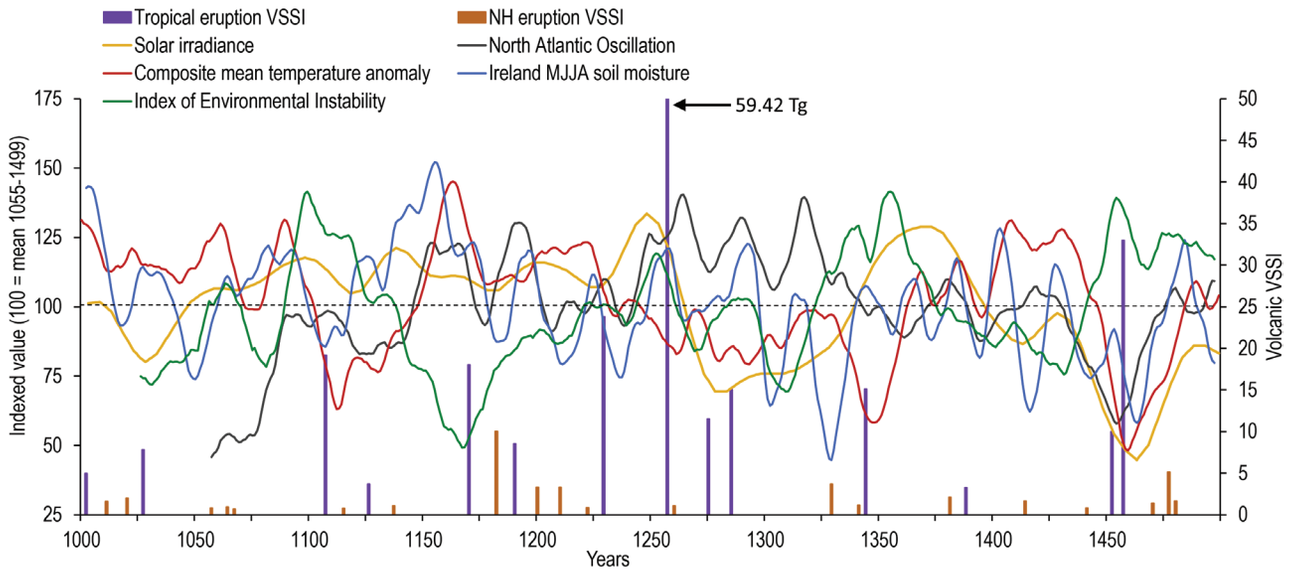

Fig. 1—Indexed solar irradiance, northern hemisphere and European temperatures, Irish spring–summer soil moisture (i.e., MJJA precipitation), the NAO and an Index of Environmental Instability, plus estimated volcanic stratospheric sulphate injections (VSSI; in mass units of teragrams, i.e., Tg) for major tropical and northern-hemisphere extratropical eruptions, 1000–1500 CE. Note the VSSI value of 59.42 for the 1257 Samalas eruption has been truncated at 50 Tg for visual clarity.

Note: temperatures, precipitation, environmental instability and the NAO are centred eleven-year moving averages.

Sources: Solar Irradiance: Friedhelm Steinhilber, Jürg Beer and Claus Fröhlich, 'Total solar irradiance during the Holocene', *Geophysical Research Letters* 36 (2009), L19704. Data: Steinhilber *et al*., 'Holocene total solar irradiance reconstruction', IGBP PAGES/World Data Center for Paleoclimatology, Data Contribution Series # 2009–133, NOAA/NCDC Paleoclimatology Program, Boulder CO, USA. www.ncdc.noaa.gov/paleo/study/8744. Accessed 25 August 2016.

Composite mean temperature anomaly: Appendix 1.

Ireland MJJA soil moisture: Appendix 2. Data downloaded from Edward R. Cook *et al*., 'Old World megadroughts and pluvials during the Common Era', *Science Advances* 1:10 (2015), e1500561. doi: 10.1126/sciadv.1500561

North Atlantic Oscillation: Appendix 3.

Index of Environmental Instability: Appendix 5.

Volcanic stratospheric sulphur injections: Matthew Toohey and Michael Sigl, 'Volcanic stratospheric sulfur injections and aerosol optical depth from 500 BCE to 1900 CE', *Earth System Science Data* 9:2 (2017), 809–31: 822.

1000 to 1500 CE spanned the Oort Solar Minimum (*c*.1010–50), Medieval Solar Maximum (*c*.1050–1265), Wolf Minimum (*c*.1282–1342), Chaucerian Maximum (*c*.1350–95) and Spörer Minimum (*c*.1416–1534), with each upturn or downturn in irradiance having potentially far-reaching consequences for global temperatures, sea-surface temperatures, ocean currents, pressure gradients and patterns

of atmospheric circulation.[23] Across these centuries, major volcanic forcing events such as those dated approximately to 1108, 1170, 1182, 1229, 1257, 1275, 1285, 1344, 1452 and 1457 triggered a series of short-term but severe climate anomalies of (sometimes) up to three years' duration that were geographically selective in their weather effects and on occasion, via sea-ice formation, may have initiated positive feedback effects of far greater duration.[24] An array of chronologies, from tree rings, speleothems, ice cores, lake sediments and other 'natural archives' (i.e., biological and physical 'proxies'), shed light on the extent to which these climate-forcing events then affected weather conditions over Ireland, Britain and adjacent parts of mainland Europe.

Thanks to research stemming from current concerns about global warming and whether or not the peak temperatures of the Medieval Climate Anomaly have now been exceeded, there are many good temperature reconstructions extending back over the whole or most of the last millennium for the northern hemisphere, the North Atlantic and continental Europe (Appendix 1). Increasingly ingenious methods have been devised for estimating both temperatures and precipitation from tree rings, but with the limitation that the results relate almost exclusively to conditions during the growing season from (broadly) March to August. Tree-ring-derived precipitation series are available for southern England and the Old World Drought Atlas has reconstructed annual patterns of spring–summer soil-moisture content across Europe from a pan-continental network of tree rings from oak and other species, from which a subsidiary chronology for Ireland can be disaggregated (Fig. 1 and Appendix 2).[25] Precipitation series have also been derived from speleothems. That inferred from a speleothem from

[23] The dates are given by Minze Stuiver and Paul D. Quay, 'Changes in atmospheric Carbon-14 attributed to a variable sun', *Science* 207:4426 (1980), 11–19; also N.R. Rogozo *et al.*, 'Reconstruction of Wolf sunspot numbers on the basis of spectral characteristics and estimates of associated radio flux and solar wind parameters for the last millennium', *Solar Physics* 203 (2001), 179–91. The reconstruction of solar irradiance by Gilles Delaygue and Edouard Bard, 'An Antarctic view of Beryllium-10 and solar activity for the past millennium', *Climate Dynamics* 36:11–12 (2011), 2201–18, supersedes that of Edouard Bard *et al.*, 'Solar irradiance during the last 1200 years based on cosmogenic nuclides', *Tellus* 52B (2000), 985–92: the correlation between the two series for the years 868–1936 is +0.897.

[24] Markus Stoffel *et al.*, 'Estimates of volcanic-induced cooling in the northern hemisphere over the past 1,500 years', *Nature Geoscience* 8:10 (2015), 784–8. For the hypothesis that the sequence of large explosive eruptions in the later thirteenth century may have initiated the Little Ice Age with reinforcement from positive Arctic sea-ice-formation feedbacks: Gifford H. Miller *et al.*, 'Abrupt onset of the Little Ice Age triggered by volcanism and sustained by sea-ice/ocean feedbacks', *Geophysical Research Letters* 39:2 (2012), L02708, and Joanna Slawinska and Alan Robock, 'Impact of volcanic eruptions on decadal to centennial fluctuations of Arctic sea ice extent during the last millennium and on initiation of the Little Ice Age', *Journal of Climate* 31 (2018), 2145–67.

[25] More formally, the Old World Drought Atlas (OWDA) offers a reconstruction of the self-calibrating Palmer Drought Severity Index (scPDSI), reflecting spring–summer

the Cnoc nan Uamh cave system in the extreme north-west of Scotland is regarded as especially diagnostic of the strength and direction of the rain-bearing winter westerlies.[26] In conjunction with evidence from more southerly latitudes, it has been used to reconstruct annual variations in the NAO (Appendix 3),[27] a dominant determinant of winter weather conditions over Ireland and the British Isles generally. More basically, the Irish oak chronology of annual ring widths spans eight millennia and provides a crude but effective barometer of annual variations in growing conditions, with oaks typically thriving under the cool and moist spring and summer conditions that were least favourable to grain production (Appendix 4). Years with wide or narrow rings may thus prove diagnostic of periods when weather conditions proved either challenging or beneficial to agricultural producers.[28]

It is likely that environmental variability, particularly when rapid and pronounced, may have as great an impact upon society as the absolute magnitude of singular weather extremes experienced historically.[29] An Index of Environmental Instability (Appendix 5), which measures how stable or otherwise prevailing climatic conditions were over time, has therefore been derived from these annual series of temperatures, growing-season soil-moisture availability and tree-ring widths. This is particularly useful for identifying the episodes of intensified environmental stress to which ecosystems and human societies were periodically exposed, as in the 1090s, 1350s and 1450s (Fig. 1).

Taken together, this array of climate variables reveals a complex picture of ongoing episodic change (Fig. 1), in which no combination of climatic circumstances ever persisted for long or recurred in quite the same configuration. The trends summarised in Fig. 1 are generalised by smoothing and hence omit the sometimes

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soil-moisture availability: E.R. Cook *et al*., 'Old world megadroughts and pluvials during the common era', *Science Advances* 1:10 (2015), e1500561.

[26] C.J. Proctor, A. Baker, and W.L. Barnes, 'A three thousand year record of North Atlantic climate', *Climate Dynamics* 19:5–6 (2002), 449–54.

[27] V. Trouet *et al*., 'Persistent positive North Atlantic Oscillation mode dominated the Medieval Climate Anomaly', *Science* 324 (2009), 78–80; Ortega, 'Model-tested North Atlantic Oscillation reconstruction'.

[28] Thus, years with moderately below average oak growth may be indicative of dry spring and early summer conditions more conducive to grain growth, but years with particularly extreme oak growth, whether negative or positive, may be considered potentially stressful for society. For example, very deep growth minima, as seen in Irish oaks in 737 and 738 CE, indicate severe drought likely to be of net harm to grain crops (Ludlow and Travis, 'STEAM approaches to climate change', 54). The detrimental character of this drought is confirmed by a continuator of Bede's *Ecclesiastical History*, who for 737 CE reports 'A great drought rendered the land infertile' (B. Colgrave and R.A.B. Mynors (eds) *Bede's ecclesiastical history of the English people* (Oxford, 1969), 573).

[29] For the impact of rapid environmental variability: A.J. Dugmore *et al*., 'The role of climate in settlement and landscape change in the North Atlantic islands: an assessment of cumulative deviations in high-resolution proxy climate records', *Human Ecology* 35:2 (2007), 169–78.

extreme annual and seasonal variations that occasionally caused so much grief to society and moved annalists to comment. Fleeting but dramatic events, such as the steeple-toppling St Maur's Day wind of 15 January 1362, 'which wrecked churches and houses and sank many ships and boats', are simply not captured at this scale of analysis, although the generally disturbed climatic context from which this particularly destructive cyclone emerged does show up quite clearly.[30]

Close scrutiny of the variations plotted in Fig. 1 reveals some striking temporal contrasts. Note, for instance, the exceptional weakness of the NAO, driver of the mild and rain-bearing winter westerlies, in the mid-eleventh century following the Oort Solar Minimum. A century later, the Medieval Solar Maximum had become firmly established, the NAO was back up to strength, temperatures and rainfall were both well above average and, with few major volcanic eruptions to perturb global circulation patterns, Ireland's weather appears relatively settled. Never again would the Index of Environmental Instability remain so low on average for so long. These stable weather patterns were eventually unsettled in the 1250s when one of the greatest of all tropical eruptions came hard on the heels of exceptionally strong solar forcing at a time when the NAO was approaching its maximum strength.[31]

Nevertheless, across these five centuries the period of most critical instability was during the middle decades of the fourteenth century, when solar irradiance swung from the low of the Wolf Minimum to the high of the Chaucerian Maximum and renewed volcanic forcing reinforced a notable climate anomaly in the 1340s.[32] The NAO decisively weakened (Appendix 3) and, as North Atlantic sea-surface temperatures alternated with ever increasing amplitude between warm and cold, temperature and precipitation patterns fluctuated between extremes and became conspicuously asynchronous (Fig. 7 and Appendices 1 and 5). The last quarter of the fourteenth century brought a return to more settled conditions, which lasted until well into the opening decades of the fifteenth century.

From the 1430s, with gathering momentum, climatic conditions changed yet again (Fig. 1). The onset of the Spörer Solar Minimum, reinforced during the

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[30] The *Annals of Ulster, of Connacht, of Loch Cé* and *of the Four Masters* all report the *gaeth mór*: Ludlow, 'Utility 2', 261. It is, however, English chronicles that supply its precise within-year date: C.E. Britton, 'A meteorological chronology to A.D. 1450', *Meteorological Office Geophysical Memoirs 70* (London, 1937), 144–5; Britton reports that according to John of Reading 'the strength of this wind did not abate for seven days and nights following' and that it came from the south and west.

[31] Clive Oppenheimer, *Eruptions that shook the world* (Cambridge, 2011), 261–7; B.M.S. Campbell, 'Global climates, the 1257 mega-eruption of Samalas Volcano, Indonesia, and the English food crisis of 1258', *Transactions of the Royal Historical Society* 27 (2017), 87–121.

[32] Campbell, *Great Transition*, 277–86. Fredrik C. Ljungqvist *et al*., 'Linking European building activity with plague history', *Journal of Archaeological Science* 98 (2018), 81–92: 86, note significantly reduced levels of felling in 1340 and 1344. For the *c*.1344 volcanic event: Michael Sigl *et al*., 'Timing and climate forcing of volcanic eruptions for the past 2,500 years', *Nature* 523 (2015), 543–9: 'Extended data', Tables 4–6.

1450s by a succession of mega eruptions, initiated the first genuinely severe and sustained cold phase of the Little Ice Age. Simultaneously, the NAO weakened decisively, temperatures and precipitation fell and instability rose. Although Irish annalists commented with awe on the 'great frosts' of 1434 and 1435 it was in the 1450s and 1460s that the circulation patterns associated with this distinctive climatic episode were at their most pronounced.[33] At the same time, plague became a recurrent scourge. These environmental circumstances were more or less the opposite of those that had prevailed in the mid-thirteenth century when the circulation patterns of the Medieval Climate Anomaly had been securely in place, delivering on average a mild and moist maritime airstream to Ireland. The evidence as presently assembled thus suggests that the fourteenth century marks the point of transition between these two very different climate regimes.

Investigating how Irish society was affected by these climatic trends and variations is contingent in large part upon the availability of written records, which are limited in survival, uneven in their chronological, geographical and thematic coverage and, for a variety of reasons, may be problematic to date. The Gaelic Annals, compiled up to (and into) the thirteenth century primarily by monastic chroniclers and thereafter by hereditary historians in the employ of the Gaelic nobility, together with the few surviving Latin chronicles of the English Lordship (collectively termed the Anglo-Irish Annals), are the one genre of record with continuous annual coverage of the entire five centuries under consideration (Fig. 2).[34] Unusual weather events are frequently recorded in the Annals, along with their biospheric and human impacts, albeit with an inevitably greater focus on the fates of high-status individuals than those of the humble majority.

Extreme weather was deemed record-worthy by Irish annalists for many reasons, but particularly for its deleterious material impacts and perceived religious significance (e.g., as divine portent or vehicle of divine retribution).[35] The uneven occurrence of extreme weather phenomena will have acted as one fundamental control on the frequency with which they were reported; their perceived relevance to unfolding human events was another.[36] There is therefore an

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[33] For descriptions in the Annals of cold conditions in 1435 and 1435: Ludlow, 'Utility 2', 271–74. Chantal Camenisch *et al*., 'The 1430s: a cold period of extraordinary internal climate variability during the early Spörer Minimum with social and economic impacts in north-western and central Europe', *Climate of the Past* 12:11 (2016), 2107–26. For conditions in the 1450s: Campbell, *Great Transition*, 371–3, and below, pp. 225–6.

[34] Daniel McCarthy, *The Irish Annals: their genesis, evolution, and history* (Dublin, 2008). For the varying temporal coverage of sixteen Irish annalistic texts: Francis Ludlow, 'Assessing non-climatic influences on the record of extreme weather events in the Irish Annals', in P.J. Duffy and W. Nolan (eds), *At the anvil: essays in honour of William J. Smyth* (Dublin, 2012), 93–133: 113.

[35] Ludlow, 'Utility of the Irish Annals', vol. 1, 149–201. See also the compilation of weather events from the Annals in Ludlow, 'Utility 2'.

[36] Ludlow, 'Assessing non-climatic influences'. The frequency of weather events (and related societal stresses such as famine and plague) represent only a small subset of

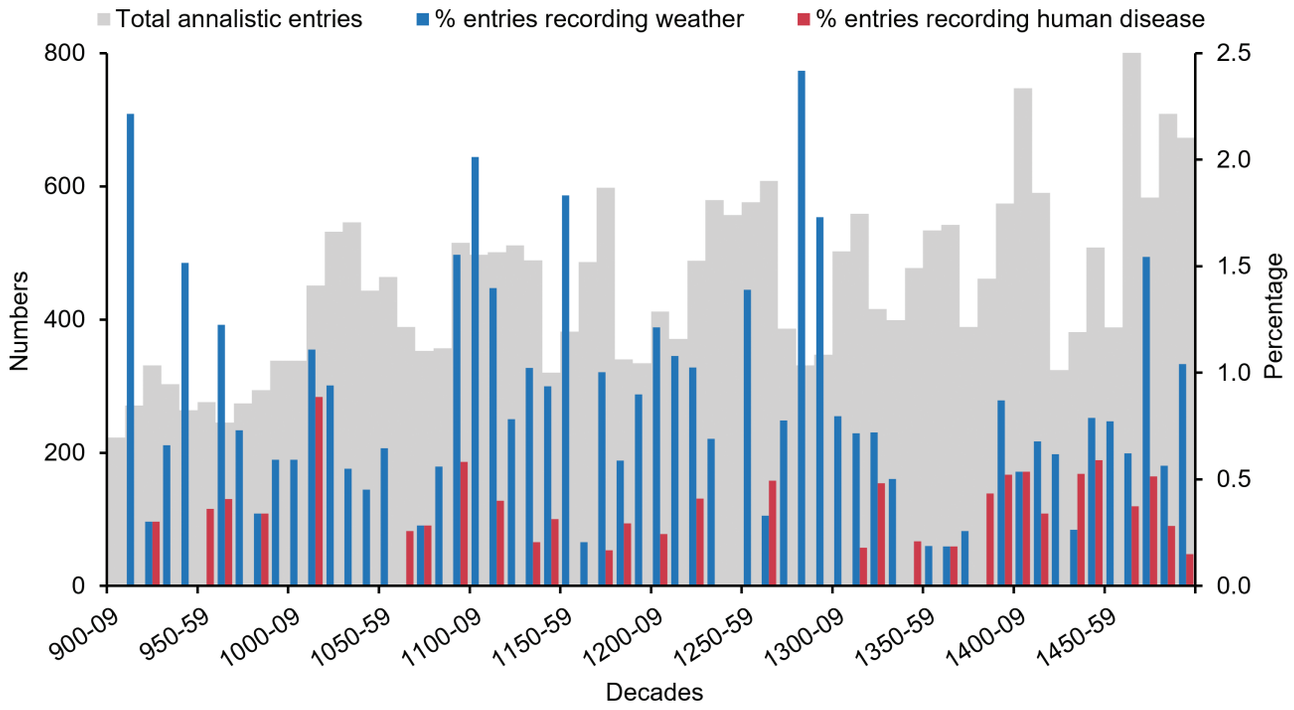

Fig. 2—Decadal totals of all Gaelic annalistic entries and the percentages of those entries recording extreme weather and human disease, 900–1500 CE.

Source: Francis Ludlow, 'The utility of the Irish Annals as a source for the reconstruction of climate', unpublished PhD thesis, Trinity College Dublin, 2010, vol. 2.

important distinction to be drawn between the frequency with which weather phenomena are reported and the frequency of their actual occurrence. Further, although events of national significance are recorded in all Annals, annalists were typically provincial in their interests with the result that there are some conspicuous regional imbalances in their collective coverage. Frustratingly, and in contrast to the situation before the English invasion, it is the more densely

the total number of reported events, yet periods with a greater surviving record density still tend to report more weather events, making climatic inferences from raw counts of weather events hazardous (e.g., see the approach and resultant interpretation of weather event frequencies offered by T.R. Kerr, G.T. Swindles and Gill Plunkett, 'Making hay while the Sun shines? Socio-economic change, cereal production and climatic deterioration in early medieval Ireland', *Journal of Archaeological Science* 36 (2009), 2868–74). One method of controlling for changes in record density is to express events as a percentage of total record availability, as per Fig. 2. In this paper it is also assumed that the more extreme the event the greater the probability that it will have been recorded and thereafter survived the process of copying through time (hence the reported frequency of the more extreme events may be less affected by record density), but the issue of recording bias merits further investigation.

populated and commercialised territories of the south and east of the country that are the least well represented (Fig. 3).

Of changes in annalistic recording tradition through time, perhaps the most important is the move from the late-thirteenth-century away from monastic recording to secular recording by hereditary Gaelic scholars. This was accompanied by a heavy (if not complete) shift in the centres of recording to the west of the Shannon and north of the island, where exposure to Atlantic and Arctic weather systems was greatest and grass-based pastoral agriculture predominated. Nonetheless, the full spectrum of extremes of temperature, wind and precipitation nominally continued to receive attention. Geographically, the resultant change in coverage is particularly evident in the case of the *Annals of Ulster* which, after *c*.1300, has significantly less to say about events within the province of Leinster and especially little within the counties of Dublin, Wicklow, Carlow and Wexford (Fig. 3). The best national coverage is therefore obtained by pooling the information contained in all the surviving Annals. Whether any of them individually were qualified to speak of conditions across Ireland as a whole, as in 1461 when the *Annals of Connacht* claimed a 'great dearth throughout Ireland', is nevertheless an open question.[37]

Few of the surviving Annals provide an entirely independent record, since much that they contain was copied from other earlier Annals and therefore reported at second and third hand, although sometimes this has the merit of providing different versions of the same event.[38] For example, the *Annals of Ulster*, *of Loch Cé*, *of Connacht* and *of Clonmacnoise* (or *Mageoghagan's Book*) all effectively repeat the same underlying original report of the frost and heavy snow that prevailed from late December 1281 to the start of February 1282. By contrast, the *Annals of Inisfallen* offer a more independent Munster perspective and add that 'there was very bad weather generally from then on, which prevented any useful work being done', not least through the 'many a violent wind-storm' that

[37] Ludlow, 'Utility 2', 276. The annalists sometimes reveal networks of information that would have provided at least a wider regional perspective. Thus for 1471 the *Annals of Connacht* report that 'Showers of hail fell each side of Beltaine [1 May], with lightning and thunders, destroying much blossom and beans and fruits in all parts of Ireland where they fell. One of these showers, in the east, had stones two or three inches long, which made large wounds on the people they struck and destroyed…and a dog in Mag Trega [Moytra, a plain in Co. Longford] and about Cluain Lis Beci [near Rathowen, Co. Westmeath] and in every place it visited. There was another, in the north, which did much damage in Moylurg [in Co. Roscommon] and at the monastery of Boyle [also Co. Roscommon]; and a boat could have floated over the floor of the great church of the monks, as we have heard from the folk of that place.' This report is also found much-abbreviated in the *Four Masters*: Ludlow, 'Utility 2', 279–80.

[38] These are often simple duplicates of lost original observations, but certain texts (or combinations of texts) may provide a fuller or more faithful account of these lost originals: McCarthy, *Irish Annals*. The complexity of this situation makes the collation of all available records a necessity, as per Ludlow, 'Utility 2'.

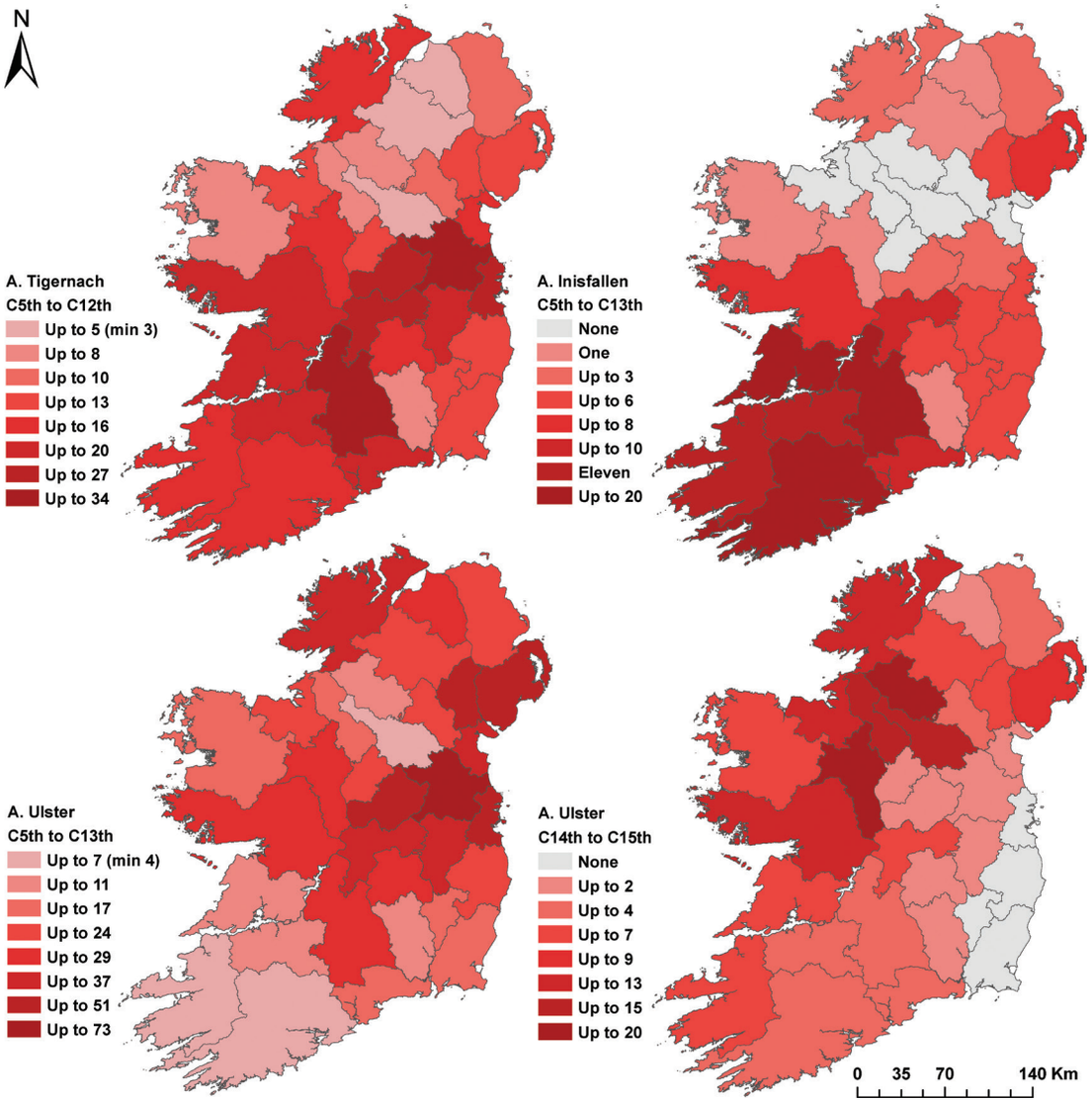

FIG. 3—The spatial coverage of entries in the *Annals of Tigernach*, fifth to twelfth centuries, *of Inisfallen* and *of Ulster*, fifth to thirteenth centuries, and again *of Ulster*, fourteenth to fifteenth centuries CE.

Note: Entries are mapped by sampling the first year of each decade, excepting in the fifth and sixth centuries, where every fifth year is mapped to compensate for lower average entry numbers in this early period. Divisions in the scale (i.e., entry numbers up to 15, 20, etc.) are generated by Jenks Natural Breaks. For expediency, modern county boundaries are used even though they are anachronistic for much of the period being mapped. Although uncertainties remain respecting the identification of many place names, and territories reported in connection with events are often poorly constrained and vary through time, most can be attributed with some confidence to a particular county or group of counties. These are still sufficiently numerous and granular to offer a broad impression of the changing spatial focus of annalistic recording.

Note also that the *Annals of Tigernach* end in 1178 and although the *Annals of Inisfallen* end in 1450, the bulk of their coverage ends in the early fourteenth century. The *Annals of Ulster*, which end in 1538, thus better reveal the shift in spatial focus to the west and north, post *c.*1300.

Source: Counts made by Francis Ludlow and Brianán Nolan for this paper.

wrought considerable damage to agriculture and infrastructure.[39] Additionally, because annalists differed in the dating conventions they followed and those conventions evolved considerably through time, there are often significant discrepancies between Annals in the precise dating of events. Transcription, translation and linguistic change can also distort the intended meaning of entries originally recorded in Old and Middle Irish or Latin.[40] Application of the chronological corrections pioneered by Daniel McCarthy and verified by reference to independently known events has, however, gone far in resolving the multiple divergent dates for the same events often seen between texts.[41] Establishing whether the multiple translations offered by the modern editors of these texts are largely in agreement can similarly resolve uncertainties of meaning and translation.[42] Calibrating weather events recorded in the Annals against relevant independent palaeoclimate proxies can further help verify their general reliability and highlight potentially significant omissions and thematic biases.

From the thirteenth century, comparing Ireland's annalistic record against the robustly documented and quantitative English record of grain prices, daily real wage rates, harvests and crop yields (for none of which are there Irish counterparts, bar scattered references in manorial extents and other records of the English colony in Ireland) can potentially serve the same validating purpose, with the advantage of revealing similarities and discrepancies between the nature and experience of climate change on opposite sides

[39] Ludlow, 'Utility 2', 237–8.

[40] An example, from duplicate entries in the *Annals of Connacht* and *of Loch Cé* for 1308, is the Irish word '*donenn*' with its adjectival variant '*doinend*'. A.M. Freeman (editor of the *Annals of Connacht* in 1944) is alone in translating this as 'storm' or 'stormy' weather, rather than a more general inclemency or badness of weather, as rendered by W.M. Hennessy for the *Annals of Loch Cé* (1871) and by multiple modern editors. P.S. Dinneen (*Foclóir Gaedilge agus Béarla: an Irish-English dictionary, being a thesaurus of the words, phrases and idioms of the modern Irish language* (Dublin, 1927, new edition), 355) translates '*doineann*' variously as 'bad weather, storm, tempest' and, in adjectival form, '*doineannac*' as 'stormy, wintry, tempestuous'. The correct choice is thus unclear, but has a bearing upon climatic reconstructions, e.g., storm chronologies, attempted using the Annals: Ludlow, 'Utility of the Irish Annals', vol. 1, 139–41.

[41] Daniel McCarthy, *Irish chronicles and their chronology* (Dublin, 2005, 4th edition), available at www.cs.tcd.ie/Dan.McCarthy/chronology/synchronisms/annals-chron.htm (last updated: 21/03/05; accessed: 06/01/18). These corrections are applied to all reports taken from the Annals, and extended to the small number of texts not fully covered by McCarthy (e.g., the *Annals of Inisfallen*, *of the Four Masters*, and *of Clonmacnoise*): Ludlow, 'Utility 2'. For further insights into the dating of the Annals: Daniel McCarthy, 'Analysing and restoring the chronology of the Irish Annals', in Ralph Kenna, Máirín MacCarron and Pádraig MacCarron (eds), *Maths meets myths: quantitative approaches to ancient narratives* (Switzerland, 2017), 177–94; Daniel McCarthy, 'The genesis and evolution of the Irish Annals to AD 1000', *Frühmittelalterliche Studien* 52 (2018), 119–55.

[42] For weather references in the Gaelic Annals, this exercise has been undertaken in Ludlow, 'Utility 2'.

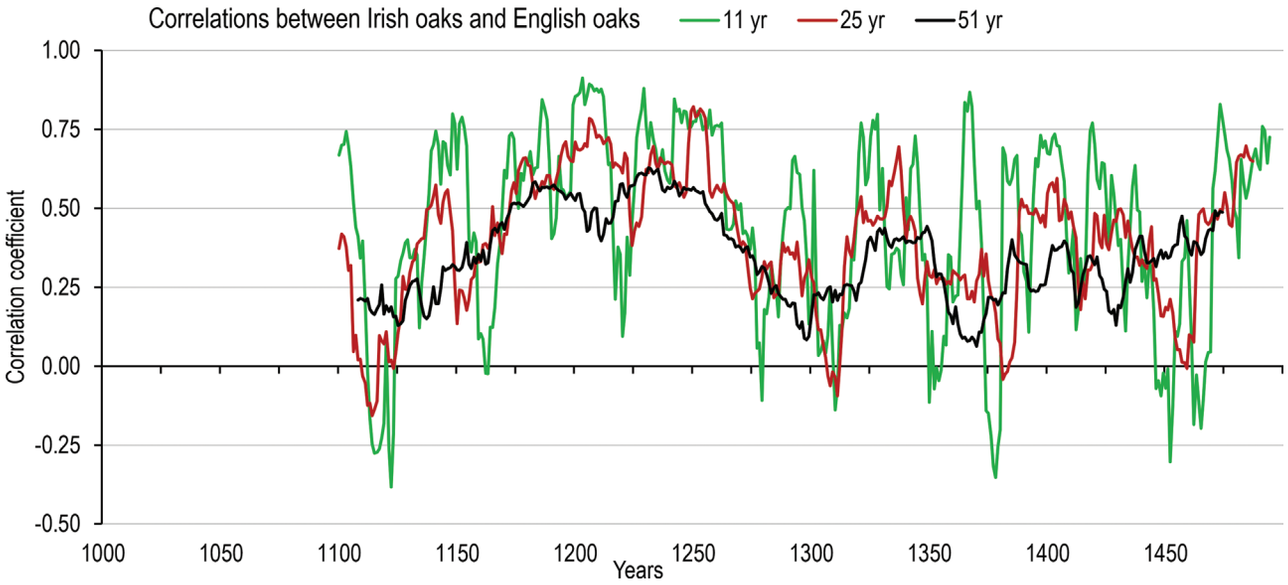

FIG. 4—Correlations between Irish and English oak ring widths, 1100–1499 CE, at different levels of smoothing.

Sources: Oak ring width data (Appendix 4) supplied by M.G.L. Baillie from the Queen's University dendrochronology database.

of the Irish Sea. This is important because it cannot be assumed that climatic trends and variability always occurred consistently across this wider region.[43] Of course, the case in principle for making such a comparison, despite some meaningful differences between the regional extremities of the north and west of Ireland versus the south and east of England, is that Ireland and England are located within a common north-west European temperate maritime climate zone. They were therefore exposed to most of the same macro-scale changes and fluctuations in climate. In different ways, they are also likely to have suffered from many of the same specific synoptic-scale extreme weather events such as the windstorms and heavy precipitation swept east by Atlantic cyclones, and particularly conditions of drought or frost from even larger-spatial-scale anti-cyclonic weather systems.

Fig. 4 demonstrates that from 1100–1499 CE, with only sporadic and brief exceptions, the ring widths of climate-sensitive Irish and southern-English oaks (i.e., those likely to exhibit least agreement) are positively correlated. Values range from a minimum of +0.23 across the fourteenth century to a maximum of +0.45 across the thirteenth century, with an overall correlation of +0.27 between 1100 and 1499. Correlations across shorter time spans

[43] Gerard Kiely *et al.*, *Extreme weather, climate and natural disasters in Ireland. Synthesis report. Climate change research programme (CCRP) 2007–2013,* Environmental Protection Agency, Report Series 5 (Wexford, 2010).

are often much higher and, irrespective of the levels of smoothing, range between +0.5 and +0.8 for much of the period 1250–75 when, significantly, the NAO was mostly strongly positive. Instances when the observed correlation between Irish and southern English oaks is weak or even inverted are both fewer and briefer and show up most clearly when correlations are calculated across short time frames of 25 years or less. Thus, the most conspicuous deviations between oak growth on opposite sides of the Irish Sea occurred in the 1110s, early 1310s, late 1370s and around 1450, with other lesser and briefer divergences focused on 1162–3, 1220, 1279, 1350 and 1465. To Mike Baillie, each inversion 'suggests that some environmental boundary has shifted … as if someone has drawn a line down the middle of the Irish Sea on a weather map' and each may therefore be diagnostic of some fundamental anomaly in North Atlantic climates.[44] The rarity of these exceptions nonetheless proves the rule that under 'normal' conditions Ireland and England exist in the same climatic region, at least as far as oak trees are concerned. Herein lies the case for matching the Irish annalistic record of bad weather, poor harvests, famines and mortality crises against the corresponding English record of harvests, wages, harvests and crop yields, provided that the comparison is not pushed too hard. Contextualising the Annals in these ways brings the information they contain (and do not contain) into sharper focus and, as the rest of this paper demonstrates, lends new significance to some of the human and environmental events that are recorded.

Climate and society 1000–1500 CE—an outline chronology

Land clearance, construction, economic expansion and population growth tended to march together, as did societal contraction, land abandonment and the re-expansion of woodland, but they rarely did so in perfect step.[45] For example, in an Irish context, counting backwards to obtain the age of oaks sampled from historical, archaeological and natural contexts suggests that much of the woodland extant in the sixteenth century had regenerated in the aftermath of the devastating plague outbreaks of the fourteenth century, as was the case in many

[44] Mike Baillie, *New light on the Black Death: the cosmic connection* (Stroud, 2006), 105 and 105–13 for a fuller discussion of the potential significance of this phenomenon.

[45] Baillie, *New light*, 21–3; Rowan McLaughlin, Emma Hannah, and Lisa Coyle-McClung, 'Frequency analyses of historical and archaeological datasets reveal the same pattern of declining sociocultural activity in 9th to 10th century CE Ireland', *Cliodynamics: The Journal of Theoretical and Mathematical History* 9:1 (2018), 1–24; F.C. Ljungqvist *et al*., 'Linking European building activity with plague history', *Journal of Archaeological Science* 98 (2018), 81–92; Eltjo Buringh *et al*., 'Church building and the economy during Europe's "Age of the Cathedrals", 700–1500 CE', *Explorations in Economic History* 76 (2020), e101316.

other parts of Europe.[46] Kenneth Nicholls subscribes to 'a considerable regrowth of woodland' following a 'collapse of the intensive colonial economy of the thirteenth century and of the population of Ireland as a whole', while suggestive palynological evidence of the landscape abandonment that may have facilitated Irish oak regeneration in the fourteenth century is also noted by Valerie Hall, albeit with some notable exceptions.[47] Dendrochronological evidence of the contraction or expansion of tree cover can therefore offer an instructive guide to the direction and timing of prevailing societal trends when, as in the case of late-medieval Ireland, independent historical evidence of the latter is fragmentary. It is thus, in an exploratory way, that it is employed here and in the certain knowledge that relationships between the dendrological and human populations were non-stationary through time and space. Its value lies in the unique chronological framework that it provides for contextualising the evidence of environmental and societal conditions contained in the Annals (compare Figs 2 and 5).

The chronological distribution of Irish oak samples dated at the dendrochronological laboratory at the Queen's University of Belfast constitutes the essential quantifiable data necessary to this task.[48] For any given year, the

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[46] David Brown and M.G.L. Baillie, 'How old is that oak?', in Ben Simon (ed.), *A treasured landscape: the heritage of Belvoir Park* (Belfast, 2005), 85–97; Baillie, *New light*, 21–3; Per Lagerås, *The ecology of expansion and abandonment: medieval and post-medieval land-use and settlement dynamics in a landscape perspective* (Stockholm, 2006), 77–92; Dan Yeloff and Bas van Geel, 'Abandonment of farmland and vegetation succession following the Eurasian plague pandemic of AD 1347–52', *Journal of Biogeography* 34:4 (2007), 575–82; Ulf Büntgen *et al*., 'Filling the Eastern European gap in millennium-long temperature reconstructions', *Proceedings of the National Academy of Sciences* 110:5 (2013), 1773–8: 1776.

[47] Kenneth Nicholls, 'Woodland cover in pre-modern Ireland', in P.J. Duffy, David Edwards and Elizabeth FitzPatrick (eds), *Gaelic Ireland c.1250—c.1650: land, lordship and settlement* (Dublin, 2001), 181–206: 202; V.A. Hall, 'The vegetation history of monastic and secular sites in the midlands of Ireland over the last two millennia', *Vegetation History and Archaeobotany* 15:1 (2006), 1–12; V.A. Hall, *The making of Ireland's landscape since the Ice Age* (Cork, 2011), 126–7.

[48] This work began in the late 1960s and by 1984 had contributed to an unbroken 7,272-year oak chronology: J.R. Pilcher *et al*., 'A 7,272-year tree-ring chronology for Western Europe', *Nature* 312:5990 (1984), 150–2. Because no other native British and Irish trees with a clearly defined annual ring pattern are as well represented by living trees, preserved timbers, and excavated and fossil timbers, oaks are almost exclusively the main species for which dendrochronologies have been developed in Britain and Ireland. A recent exception is a native pine chronology for the northern Cairngorms of Scotland: Miloš Rydval *et al*., 'Reconstructing 800 years of summer temperatures in Scotland from tree rings', *Climate Dynamics* 49:9–10 (2017), 2951–74. For a pilot study of the use of multiple species in Ireland (e.g., beech and ash) to derive a clearer climate signal than that embedded in oak chronologies alone: A.M. García-Suárez, C.J. Butler and M.G.L. Baillie, 'Climate signal in tree-ring chronologies in a temperate climate: a multi-species approach', *Dendrochronologia* 27 (2009), 183–98.

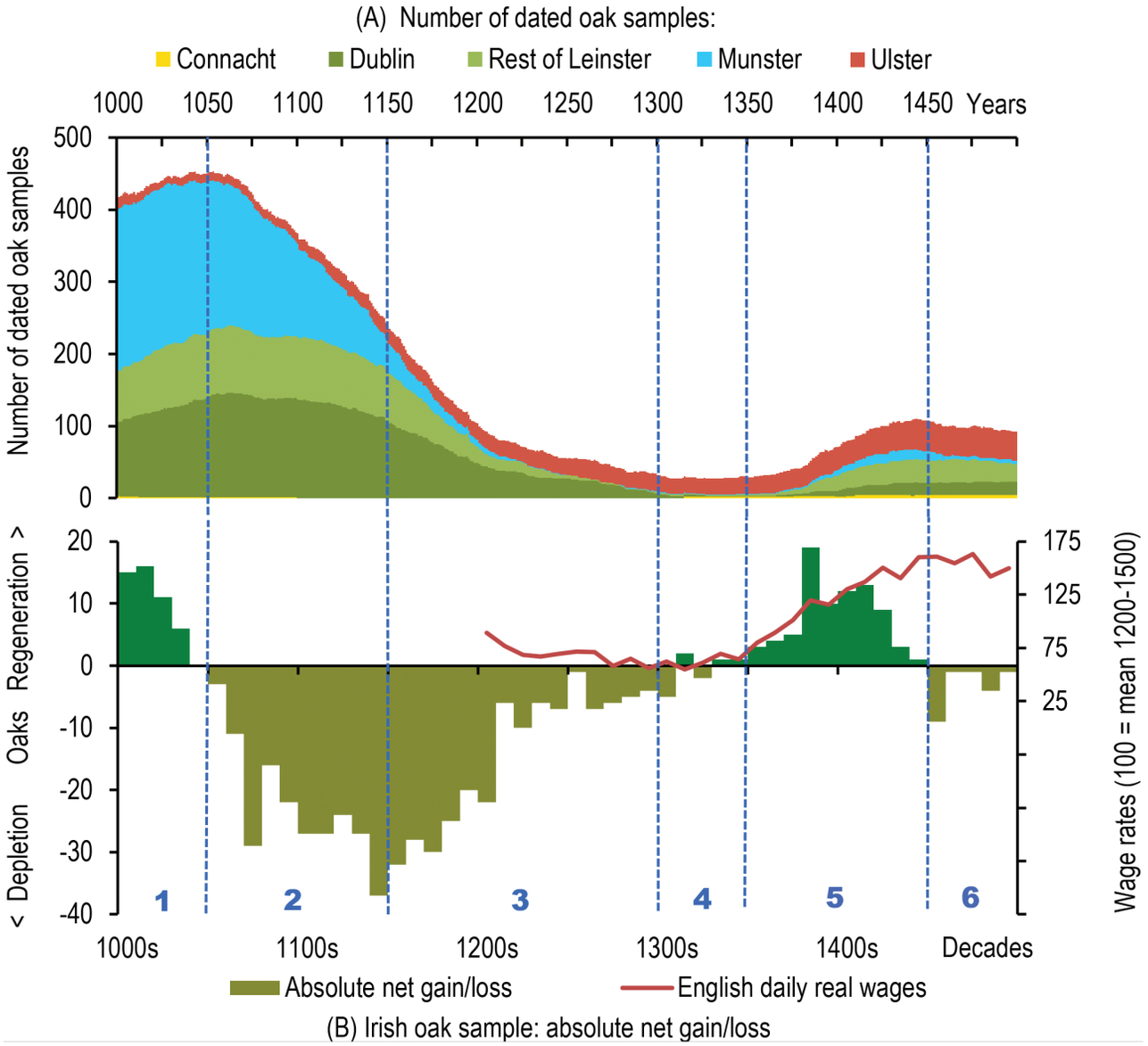

FIG. 5—(A) Numbers of dated annual Irish oak samples by province. (B) The decadal net balance between the start and end dates of sampled timbers, 1000–1500 CE with the daily real wage rates of English adult male labourers, 1200–1500 CE.

Key: 1 = regeneration; 2 = depletion phase 1; 3 = depletion phase 2; 4 = stasis; 5 = regeneration; 6 = stasis.

Note: Connacht is scarcely visible in Panel B due to the small number of samples.

Sources: Oak sample data supplied by David Brown of the Queen's University dendrochronology laboratory.

English adult male daily real wage rates calculated from: Gregory Clark, 'English prices and wages 1209–1914', Global Price and Income History Group (Davis, 2009), www.iisg.nl/hpw/data.php#united; J.H. Munro, 'The Phelps Brown and Hopkins "basket of consumables" commodity price series and craftsmen's wage series, 1264–1700: revised by J.H. Munro' (Toronto, no date), www.economics.utoronto.ca/munro5/ResearchData.html.

number of dated oak samples retrieved from archaeological excavations and historical structures provides a crude index of the number of oak trees then growing which, evidence suggests, tended to expand when human population levels were low and construction activity was slack, and contract when settlement was expanding and levels of economic activity were rising (Fig. 5A).[49] Since all dated timbers have a start and an end date (although the latter is rarely the exact felling date), for each year the net balance struck between the numbers of trees starting or ending their lives indicates whether oak numbers were increasing or decreasing (Fig. 5B).[50] Thus, when felling exceeded regeneration, the implication is that woodland depletion was ongoing, as trees were cleared for construction, fuel, agriculture and the lumber trade, whereas the opposite conditions prevailed when regeneration was in excess and populations and economic activity were in retreat (note the similar course charted by English daily real wage rates—Fig. 5B—which likewise were driven by changing land to labour ratios).

Together these measures have the merit of chronological accuracy but are qualified by the fact that the sampled oaks reflect patterns of archaeological survival and the excavation opportunities and priorities of archaeologists. It is therefore no surprise that 54 per cent of the dated samples derive from sites and excavations in Leinster, with more than half of these from Dublin alone, followed by 31 per cent from Munster, where samples from the urban sites at Cork and Waterford bulk large, 14 per cent from Ulster (notwithstanding the location of the dendrochronology laboratory within that province) and less than 1 per cent from Connacht.[51] These biases mean that the absolute magnitude of trends should not be interpreted too literally, although it is notable, and indeed reassuring, that all the regions display effectively the same chronological pattern (Fig. 5A). The geographical composition of the sample also changes over time and is least representative of Ireland as a whole, or at least of its most closely settled parts, during the critical first half of the fourteenth century (Fig. 5A). Most likely this was because the most heavily settled regions were the most denuded of oaks by this time. By its nature, therefore, this evidence must be considered a better guide to relative trends in, rather than absolute levels of, human population and/or associated construction activity. As will be noted, however, a clear six-part chronology emerges from the results set out in Figs 5A and 5B.

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[49] Baillie, *New light*, 21–3; Ljungqvist, 'Linking European building activity with plague history'; Lagerås, *Ecology of expansion and abandonment*, 77–92.

[50] Most of these end dates will not strictly represent the final year of growth because only a minority of the oak samples contain the last ring out to the bark: Ljungqvist, 'Linking European building activity with plague history', 82–3. Limiting analysis to these samples would improve the chronological precision of the results but at the expense, in the Irish case, of sample size and spatial and chronological coverage, i.e., it would refine without fundamentally changing the basic trends.

[51] The Ulster location of the Queen's dendrochronological laboratory is evident in a larger number of samples taken from natural contexts such as lake and bog margins in and near the province, but primarily pertaining to periods before 1000 CE.

Pre 1050—relative resource abundance

When the first millennium dawned, the number of then-living oaks represented in the Irish oak dendrochronology dataset was close to its late-medieval maximum. As Fig. 5A shows, many oaks felled in later centuries were actively growing at that time.[52] Because regeneration exceeded depletion (Fig. 5B), the number of precisely dated ring-width observations continued to rise to a temporal peak in the 1040s and 1050s. No subsequent period in the second millennium is better documented, with one plausible inference being that oak woodland was abundant because population was comparatively scarce and building in oak consequently slack.[53] One of the more remarkable statements in the Annals for explicitly documenting a mass internal migration is given by the *Annals of Inisfallen* for 1004 (a year of conspicuously limited Irish oak growth in Ireland).[54] It reports that 'The Ulaid [a people in eastern Ulster] abandoned their land on account of scarcity and scattered throughout Ireland', conveying an impression of a sparse and (when needed) highly mobile population responding to environmental stress. Available palynological evidence from the north of Ireland is consistent with such a reading, which also accords with the telling absence from the dendrochronological record from the 930s to the 1020s of almost any building using newly felled oaks.[55]

Also plausibly linked to this regeneration phase is the potential cumulative impact of an increase in violence and conflict reported in the Annals. Initially this is associated with Viking-related violence from approximately 910 to 950 CE, with peaks in the 920s–930s and 940s.[56] Thereafter, an escalation can be seen in vio-

[52] The situation in Scotland was much the same: Anne Crone and Fiona Watson, 'Sufficiency to scarcity: medieval Scotland, 500–1600', in C.T. Smout (ed.), *People and woods in Scotland: a history* (Edinburgh, 2003), 60–81: 80; C.M. Mills and Anne Crone, 'Dendrochronological evidence for Scotland's native timber resources over the last 1000 years', *Scottish Forestry* 66:1 (2012), 18–33: 22, 30.

[53] Note that England in 1086 supported a historically small population of under two million, which, by extrapolation, implies that Ireland's population was less than 0.75 million and quite possibly less than 0.5 million: Stephen Broadberry *et al*., *British economic growth 1270–1870* (Cambridge, 2015), 6–8; B.M.S. Campbell, 'Benchmarking medieval economic development: England, Wales, Scotland, and Ireland *circa* 1290', *Economic History Review* 61:4 (2008), 896–945: 930–2.

[54] The year 1004 exhibits the fourth narrowest oak growth-ring in the eleventh century, in a detrended oak growth chronology (by application of a 30-year cubic spline); data supplied by Mike Baillie, in personal communication with F. Ludlow, 22 December 2003.

[55] V.A. Hall, J.R. Pilcher and F.G. McCormac, 'Tephra-dated lowland landscape history of the north of Ireland, AD 750–1150', *New Phytologist* 125:1 (1993), 193–202; J.P. Mallory and M.G.L. Baillie, '*Tech nDaruch*: the fall of the House of Oak', *Emania: Bulletin of the Navan Research Group* 5 (1988), 27–33; M.G.L. Baillie and D.M. Brown, 'Dendrochronology and Deer Park Farms' in C.J. Lynn and J.A. McDowell (eds), *Deer Park Farms: the excavation of a raised rath in the Glenarm Valley, County Antrim (Northern Ireland)*, Northern Ireland Archaeological Monographs (Belfast, 2011), 558–67: 560; D.M. Brown and M.G.L. Baillie, 'Confirming the existence of gaps and depletions in the Irish oak tree-ring record', *Dendrochronologia* 30 (2012), 85–91: 88.

[56] Violence in the *Annals of Ulster* is charted by Matthew Stout, *Early medieval Ireland 431–1169* (Dublin, 2017), 139, 173.

lence from *c*.950–*c*.1050 CE, including the murder of members of the elite, mass killings and large-scale devastations of territories, which is frequently associated with dynastic rivalry for the high-kingship of Ireland.[57] Persistent slave raiding to supply the Dublin export trade must also have stoked a sense of insecurity and sapped populations of their demographic vitality.[58] McLaughlin, Hannah and Coyle-McClung have proposed that the shrinking volume of material evidence over this period,[59] along with a thinning of entries in the Annals (Fig. 2), implies a persistent downward trend in socio-cultural activity.[60] For reasons that will require much further multidisciplinary effort to resolve, society in this period appears caught in a low-equilibrium trap characterised by endemic violence, low and possibly declining population densities and an inability to capitalise upon what seem to have been increasingly favourable land to labour ratios.[61] It was from this low base and relative abundance of natural resources that, from the mid-eleventh century, renewed expansion was launched, as signalled, on the one hand, by an archaeologically well-documented upsurge in new construction activity, especially in the Hiberno-Norse towns of Dublin, Waterford and Cork, and, on the other, the diminution of violence recorded by the Annals.

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[57] This is observed in the counting of such events for the analysis presented in Appendix 6. For a classic account of the contestation for the high kingship: F.J. Byrne, *Irish kings and high-kings* (Dublin, 2001, revised edition).

[58] Poul Holm, 'The slave trade of Dublin, ninth to twelfth centuries', *Peritia* 5 (1986), 317–45; Poul Holm, 'Slaves', in Seán Duffy (ed.), *Medieval Ireland: an encyclopedia* (New York and London, 2005), 430–1.

[59] For a specific example of material-archaeological evidence in the form of grain-drying kilns, excavated and radiocarbon-dated in large numbers during the Celtic Tiger construction boom: Scott Timpany, Orla Power and Mick Monk, 'Agricultural boom and bust in medieval Ireland: plant macrofossil evidence from kiln sites along the N9/N10 in County Kildare' in Sheelagh Conran, Ed Danaher and Michael Stanley (eds), *Past time, changing fortunes: proceedings of a public seminar on archaeological discoveries on national road schemes, August 2010* (Dublin, 2011), 73–83; Mick Monk and Orla Power, 'More than a grain of truth emerges from a rash of corn-drying kilns?', *Archaeology Ireland* 26:2 (2012), 38–41. The date distribution of kilns shows an early-medieval peak followed by a (regionally variable) decline that may reflect some of the same processes driving the observed oak regeneration phase and tenth- to early-eleventh-century hiatus in oak building.

[60] McLaughlin, Hannah, and Coyle-McClung, 'Frequency analyses of historical and archaeological datasets', 11–12, 17. The authors study the *Annals of Ulster* and observe a declining number of entries centred in the tenth century. Given the differing spatial foci of the extant Annals (e.g., Fig. 3), and given that other compilations such as the *Annals of the Four Masters* include lost sources not incorporated into the *Annals of Ulster* during its own compilation from 1498 onward, there is a need to examine the changing density and geography of recording in as many texts as possible. Here, word counts may prove a useful alternative metric to event counts: E. Purcell, 'Ninth-century Viking entries in the Irish annals: "no 'forty years' rest"' in John Sheehan and Donnchadh Ó Corráin (eds), *The Viking age: Ireland and the west* (Dublin, 2010), 322–37: 323–4).

[61] It has been suggested that Ireland had a population of 0.5 million *c*.1000: Margaret Murphy, 'The economy', in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 385–414: 387.

Why an increasingly favourable land to labour ratio should for so long have failed to elicit a positive demographic response is an enigma. Political instability and the violence it engendered must have been a factor. Recurrent raiding to supply the export trade in slaves will certainly have been corrosive.[62] There are also sporadic reports in the Annals of heavy disease-related mortality in the tenth and eleventh centuries that may further have destabilised society, notwithstanding that this was an era free from bubonic plague.[63] Whether these events precipitated or otherwise contributed to any substantial depopulation on the basis of the available descriptions invites closer examination.

The weather, by contrast, seems not to have been as deserving of comment by the annalists. Although solar irradiance, likely a prime driver of global climates, was subsiding from the 960s there was a lag of some decades before a corresponding decline in northern hemisphere, North Atlantic

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[62] Holm, 'Slave trade of Dublin'; Holm, 'Slaves'; Benjamin T. Hudson, 'The changing economy of the Irish Sea province', in Brendan Smith (ed.), *Britain and Ireland 900–1300: insular responses to medieval European change* (Cambridge, 1999), 39–66: 49–50.

[63] Examples (non-exhaustive, and focusing on apparent epidemics rather than reports of important individuals dying of disease) include: 987 (*Annals of the Four Masters*, also *of Tigernach* and *Chronicon Scotorum*): 'Preternatural (i.e. magical) sickness [was brought on] by demons in the east of Ireland, which caused mortality of men plainly before men's eyes'. 993 (*Annals of Ulster*, also *of Clonmacnoise* and *Chronicon Scotorum*): 'A great mortality of people, cattle, and bees throughout Ireland this year'. 1012 (*Annals of the Four Masters*, also *of Ulster* and *Chronicon Scotorum*): 'A great malady, namely, lumps and griping, at Armagh, from Allhallowtide [31 October] till May, so that a great number of the seniors and students died, together with Ceannfaeladh of Sabhall, bishop, anchorite, and pilgrim; Maelbrighde Mac-an-Ghobhann, lector of Armagh; and Scolaighe, son of Clercen, a noble priest of Armagh. These and many others along with them died of this sickness'. 1019 (*Annals of Inisfallen*): 'A great pestilence, i.e. a colic, in Ára [Aran Islands, Galway] in the above year, and many people died there'. 1061 (*Annals of Tigernach*, also *of the Four Masters* and *Chronicon Scotorum*): 'A great pestilence in Leinster, to wit, the smallpox and colic, so that there was a destruction of people throughout Leinster.' 1084 (*Annals of Tigernach*): 'A great pestilence in this year, which killed a fourth of the men of Ireland. It began in the south, and spread throughout the four quarters of Ireland. This is the *causa causans* of that pestilence, to wit, demons that came out of the northern isles of the world…'. This entry continues at length with mythological and fantastical elements that suggest its veracity should be carefully considered. 1095 (*Annals of Ulster*, also *of Loch Cé*, *of the Four Masters*, *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*), *of Inisfallen* and *Chronicon Scotorum*): 'A great sickness in Ireland that killed many people, [lasting] from the first of August until the following May Day—i.e. the year of the mortality'. Ludlow, 'Utility 2', 143–4, 146, 156–9, 161–4. The events of 1012 are misattributed to 1013 in Ludlow's compilation. The quoted entry in the *Four Masters* for 1012 (an apparent conflation of the earlier and perhaps part-independent entries from the *Annals of Ulster* and *Chronicon Scotorum*) is also omitted. So too is the 1019 event from the *Annals of Inisfallen*. Note that Ludlow's compilation explicitly focuses on extreme weather and conditions of famine and scarcity (which often, but not always, overlap in years of epidemic disease). A full compilation of disease reports from the Annals is thus long overdue.

sea-surface and European summer temperatures set in (Appendix 1). In fact, temperatures rose to a peak of warmth in the 980s and only then slowly began to cool, with the result that they were all still above average when the new millennium opened. Cooling then set in and in Europe the summers of 1014, 1017, 1029, 1032 and 1046 were notably chilly and also, in the main, dry over the British Isles.[64] This probably coincided with a significant weakening of the NAO, facilitating ingress of the cold winter weather reported in the Annals in 1008, 1026, 1031 and 1047.[65] Despite these changes in circulation patterns, growing-season precipitation appears to have held up well in many years, to the extent that in 1012 the *Annals of Inisfallen* complained of a great downpour, and in 1037 the *Annals of Clonmacnoise* observed that 'It rained much this summer'.[66]

The Annals suggest that perhaps the most testing years concerning food security were 1016 and 1047. The former may have been the part result of climate forcing from a possible cometary impact in 1014 and was a year notable for spring–summer drought, when the *Annals of Clonmacnoise* reported 'a great scarcity of corn and victuals this year in Ireland'.[67] A generation later, the latter year witnessed the return of 'great famine' to Ulster, associated at least partly with heavy snowfall and cattle mortality between December 1046 and March 1047, when, according to both the *Chronicon Scotorum* and *Annals of Tigernach*, 'Ulster was almost wholly devastated, and its people went into Leinster'.[68] By the yardstick of other extreme years, however, neither year stands out in the palaeoclimatic record as experiencing a major climate forcing event. Rather, on the testimony of the Annals, it is the responses to these climatic conditions that were dramatic. Society was certainly fortunate in not having to contend with the serious short-term effects of a major tropical or northern hemisphere explosive eruption. The last such volcanic events on any serious scale had been the major Icelandic eruption of Eldgjá in *c.*939 CE and the Volcanic Explosivity Index 7 (VEI7) eruption of Changbaishan on the Chinese/North Korean border seven

[64] J. Luterbacher *et al.*, 'European summer temperatures since Roman times', *Environmental Research Letters* 11:2 (2016), L024001 (data: www.ncdc.noaa.gov/paleo/study/19600; accessed 19/08/2016). The OWDA suggests conditions of widespread soil-moisture deficit for much of north-west Europe in 1014, 1017 and 1046. 1032 is similarly dry over north-west Europe, though parts of Ulster and the Irish midlands seem to have escaped. 1029 stands out as the exception, with average- to above-average soil-moisture across Ireland, though parts of Britain and northern Europe experienced drought (Cook, 'Old World megadroughts').

[65] Ludlow, 'Utility 2', 145, 149–50, 152–4.

[66] Ludlow, 'Utility 2', 146, 151. The wet spring–summer conditions of 1012 and 1037 are also amply documented in the OWDA (Cook, 'Old World megadroughts'.)

[67] For the 1014 extra-terrestrial event: Baillie, *New light*, 118–25; Baillie and Brown, 'Dendrochronology and Deer Park Farms', 565–7. Ludlow, 'Utility 2', 147.

[68] Ludlow, 'Utility 2', 152–3.

years later in *c*.946 CE.[69] Any persistent climatic constraints upon Irish society at this time are, therefore, elusive of identification and it is the recurrent and self-perpetuating dynastic warfare, slave raiding and other predatory human actions that may be posited as more likely thwarting renewed expansion and growth, with the role of epidemic disease remaining an open question.

Paradoxically, expansion eventually began during the final years of the Oort Minimum of *c*.1010–1050 (although moderate relative to later minima (Fig. 1)) and when the NAO—source of winter mildness—was exceptionally weak (Fig. 1). What role these environmental developments played in helping to kick-start growth awaits closer investigation. Perhaps these were largely coincidental as Ireland was belatedly drawn into European-wide currents of expansion, as existing constraints upon growth were relaxed, and societies across the continent were reinvigorated?[70]

1050–1150—expansion, phase one

In Ireland, as in much of Europe, the mid-eleventh century brought an unmistakable change in trends, when, on the evidence of the Irish dendrochronological record, a sustained expansion of construction activity began which was to last until the end of the thirteenth century.[71] This is marked by an implied switch from net regeneration to net depletion, as sustained felling made inroads into Ireland's oak woodlands (Fig. 5). This interpretation is reinforced by the European-wide building boom known at this time, which in Italy, France, Germany and the Southern Low Countries shows up most conspicuously in the widespread building and rebuilding of churches. Church building in all these regions increased both absolutely and relatively per head of population.[72] References to church buildings in the Annals (all physically far smaller than their European counterparts) can also be seen to increase steadily from *c*.1010.[73] This reinforces the interpretation that the dramatic increase in excavated Irish oak timbers represents the indelible signature of a corresponding increase in building activity, both in the Hiberno-Norse

[69] Chunqing Sun *et al*., 'Ash from Changbaishan millennium eruption recorded in Greenland ice: implications for determining the eruption's timing and impact', *Geophysical Research Letters* 41:2 (2014), 694–701; Matthew Toohey and Michael Sigl, 'Volcanic stratospheric sulfur injections and aerosol optical depth from 500 BCE to 1900 CE', *Earth System Science Data* 9:2 (2017), 809–31: 814.

[70] For the upward trajectory of European population trends from the eleventh century: Campbell, *Great Transition*, 58–60; B.M.S. Campbell, 'From boom to bust: the Lordship of Ireland and the European "commercial revolution"', in Peter Crooks and Seán Duffy (eds), *Invasion 1169* (Dublin, forthcoming).

[71] Baillie and Brown, 'Dendrochronology and Deer Park Farms', 559–60; Brown and Baillie, 'Confirming the existence of gaps and depletions', 88.

[72] Buringh *et al*., 'Church building and the economy'.

[73] Tomás Ó Carragáin, *Churches in early medieval Ireland: architecture, ritual and memory* (New Haven, CT, 2010), 111.

trading towns of Dublin, Waterford, Cork and Limerick and more generally.[74] The upshot was a steep increase in oak depletion rates to a maximum in the 1140s and a concomitant decline in the annual number of dated oak samples contained in the dendrochronology dataset. The implication is that sustained felling was eroding the number of standing trees, which would help explain the switch from church-building in wood to building in stone evident from 1050–69, as documented in the Annals, with references to wooden churches almost disappearing from the record after 1110.[75]

Elsewhere in Europe, these years from the 1050s to the 1140s mark the initial and most pronounced phase in the great high-medieval cycle of demographic and commercial growth, when populations and settlement evidently expanded almost everywhere and woodland, felled for timber and firewood and cleared for farmland, retreated.[76] On the available archaeological evidence, Ireland appears to have been no exception. The Viking menace had receded, slave raiding had abated, the Hiberno-Norse trading towns were thriving, and important political developments were also afoot with the emergence of an increasingly viable, if still contested, high kingship.[77]

Climatically, these years coincide with the opening phase of the Medieval Solar Maximum, when sustained high levels of solar irradiance powered the patterns of atmospheric circulation—a mostly positive El Niño Southern Oscillation, a strong South Asian monsoon, an arid Central Asia and a mostly-positive NAO—which gave the Medieval Climate Anomaly its distinctive character.[78] For Ireland this implies that from the late-eleventh century winters became on average milder and moister, as the winter westerlies strengthened, so that Ireland became significantly wetter than England. North-west Scotland experienced a similar increase in precipitation at this time but correlations between the ring widths of Irish and English oaks weakened (Fig. 4). Under these circumstances it is hardly surprising that references to drought are largely absent from the Annals. The sole exception is the hot and dry summer of 1129 already referred to, conditions which at Athlone may have been seized upon to facilitate construction of a new bridge across the River Shannon.[79] Temperatures were less buoyant and trended down, with significant drops in

[74] For a comparable situation in Scotland: Crone and Watson, 'Sufficiency to scarcity', 80.
[75] Ó Carragáin, *Churches in early medieval Ireland,* 110–11.
[76] Campbell, *Great Transition*, 30–133; H.C. Darby, 'The clearing of the English woodlands', *Geography* 36:2 (1951), 71–83.
[77] H.B. Clarke, 'Gaelic, Viking and Hiberno-Norse Dublin', in Art Cosgrove (ed.), *Dublin through the Ages* (Dublin, 1988), 4–24; Holm, 'Slave trade of Dublin'; Duffy, 'Ireland, *c*.1000–*c*.1100'; Byrne, *Irish kings and high-kings*; Stout, *Early medieval Ireland*, 215–40.
[78] Campbell, *Great Transition*, 36–58.
[79] Above, pp. 161–2. 1129 (*Annals of the Four Masters*, also *of Inisfallen*, *of Boyle* and the *Chronicon Scotorum*): 'The castle of Athlone and the bridge were erected by Toirdhealbhach Ua Conchobhair in the summer of this year, i.e. the summer of the drought': Ludlow, 'Utility 2', 176.

North Atlantic sea-surface temperatures and European growing-season temperatures in the 1070s and again during the opening quarter of the twelfth century (Appendix 1): 1107 was cold and 1109 and 1127, following major (probably tropical) eruptions in 1108 and 1126, especially so (Fig. 1).[80]

The period was not, therefore, without setbacks. The worst, as based upon the descriptions provided in the Annals, were in 1050 (inclement weather leading to dearth and triggering societal instability),[81] 1099 (famine widespread across Ireland),[82] 1107 (mass cattle and human mortality from wind and cold, and scarcity of grain from wet weather),[83] 1115–16 (a cold winter with mass mortality of wild and domestic animals, and humans, followed by famine and pestilence and claims of cannibalism),[84] 1133 (mass cattle mortality),[85] and 1137

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[80] Sébastien Guillet *et al*., 'Climatic and societal impacts of a "forgotten" cluster of volcanic eruptions in 1108–1110 CE', *Scientific Reports* 10:6715 (2020), doi:10.1038/s41598-020-63339-3 (which discusses the complexity of the ice-core volcanic signals starting in 1108); Stoffel, 'Estimates of volcanic-induced cooling', Table S4; Sigl, 'Timing and climate forcing of volcanic eruptions', 'Extended data', Tables 4–6; Toohey and Sigl, 'Volcanic stratospheric sulfur injections', 822. Francis Ludlow thanks Matthew Toohey for making a copy of the original dataset available to him. Note that Toohey and Sigl place some probable tropical eruptions a year earlier than dated by Sigl, the better to account for potential transport times of sulphate from tropical locations to the polar ice sheets.

[81] 1050 (*Annals of the Four Masters*), quoted in full above, p. 162: Ludlow, 'Utility 2', 154. This example and the linkage between weather and violence is noted by Elizabeth Fitz-Patrick, 'Raiding and warring in monastic Ireland', *History Ireland* 1:3 (1993), 13–18: 17.

[82] 1099 (*Annals of Loch Cé*, also *of Ulster*): 'Great famine throughout all Erinn in this year': Ludlow, 'Utility 2', 166.

[83] 1107 (*Annals of Ulster*, also *of Loch Cé*): 'Much wet and bad weather in this year, and it ruined the corn'; 1107 (*Chronicon Scotorum*, also *Annals of Tigernach*, and *of the Four Masters*): 'Great wind and lightning in Ireland this year, and it killed many people and cattle'; 1107 (*Annals of Ulster*, also *of Loch Cé*): 'Snow fell for a day and a night on the Wednesday before the feast of St. Patrick [17 March], and inflicted slaughter on beasts in Ireland': Ludlow, 'Utility 2', 167–8.

[84] 1115 (*Annals of Ulster*, also *of Loch Cé*, *of the Four Masters*, *Chronicon Scotorum* and *of Boyle*): 'Extremely bad weather in the form of frost and snow from the fifth of the Kalends of January [i.e., 28 December] to the fifteenth of the Kalends of March [i.e., 15 March], or a little longer, and it inflicted slaughter on birds and beasts and men, and from this great want arose throughout all Ireland, and particularly in Laigin [Leinster]'. 1116 (*Annals of Ulster*, also *Chronicon Scotorum*, *Annals of Tigernach*, *of the Four Masters* and *Mac Carthaigh's Book*): 'a great pestilence; hunger was so widespread in Leth Moga [the southern half of Ireland], both among Laigin [Leinster] and Munstermen, that it emptied church and forts and states, and spread throughout Ireland and over sea, and inflicted destruction of staggering extent': Ludlow, 'Utility 2', 173–4.

[85] 1133–4 (*Annals of Loch Cé*, also *of the Four Masters* and *Chronicon Scotorum*) 'A great cow mortality occurred throughout all Erinn, for which no likeness was found since the great cow mortality came before that in the time of Flaithbertach, son of Loingsech; and 432 years [elapsed] between them': Ludlow, 'Utility 2', 179–80. For the cited precursors of this cattle mortality, first reported in England in 699 CE and reappearing down to 708 CE in Ireland: Ludlow, 'Utility 2', 60–73; also Chaochao Gao *et al*., 'Reconciling

(disease, scarcity, attacks by wolves and human and animal mortality from severe wind).[86] Note, however, that on the evidence of the Annals, in the space of 100 years there were only half-a-dozen years of environmentally related difficulty that are explicitly documented as more than local or regional in their impact. Alone, 1115–16 unequivocally stands out as a back-to-back crisis, with the worst of its effects apparently confined to Munster and south Leinster.[87] The *Annals of Clonmacnoise*, *of Tigernach*, *of Ulster* and *of the Four Masters* all reported that Laigin [Leinster] was almost emptied of people as its population took flight and migrated to wherever they could find succour and refuge in Ireland and overseas.[88] Good years generally attracted less comment in the Annals. For instance, following the scarcity of 1107, relief is apparent in the report of the *Annals of Loch Cé* that 1108 was 'A sappy year, with good weather, and with much corn and produce', and in 1130, after a year of drought, the same text noted 'A great crop of every kind of produce generally in Erinn this year'.[89] Whereas years of benign weather afforded opportunities for recovery, none of the bad years can be seen to have inflicted a reversal so general and severe that the prevailing momentum of expansion was more than briefly interrupted.

Two of the worst setbacks—those of 1115–16 and 1137—were possibly triggered or compounded by short-term volcanic forcing from northern hemisphere eruptions dating to the same years.[90] This was a recurrent pattern.[91] On both occasions it elicited in response an increased resort to, and perhaps

multiple ice-core volcanic histories: the potential of tree-ring and documentary evidence, 670–730 CE', *Quaternary International* 394 (2016), 180–93.

[86] 1137 (*Annals of Loch Cé*): 'A great colic disease in Erinn generally, which killed many'; 'A great scarcity in the province of Connacht, *et multi mortui sunt ab ea*'; 1137 (*Annals of Tigernach*): 'The Blind One of…that is, Gilla Maire, was killed by wolves'; 1137 (*Annals of the Four Masters*, also *of Loch Cé* and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)): 'A great wind-storm throughout Ireland, which prostrated many trees, houses, churches, and buildings, and swept men and cattle into the sea, in Magh-Conaille [centred in County Louth]': Ludlow, 'Utility 2', 180–1. Other, perhaps more regionally specific stresses (e.g., cattle mortality) and weather events (e.g., lightning strikes) without documented widespread impacts are also noted across these years, with their abundance at least partly the result of the fuller recording provided by the Annals in this period (Fig. 2).

[87] It is unclear whether the conditions reported in 1115 started in late-December 1114 or late-December 1115. Determining which annual winter season is described is a recurring challenge in medieval annals: Michael McCormick, P.E. Dutton and Paul Mayewski, 'Volcanoes and the climate forcing of Carolingian Europe, A.D. 750–950', *Speculum* 82 (2007), 865–95: 876.

[88] Ludlow, 'Utility 2', 173–4. The *Annals of Tigernach* provide a unique observation of 'A murrain great and sudden, and most tormenting diseases in this year': Ludlow, 'Utility 2', 172.

[89] Ludlow, 'Utility 2', 169, 177–9.

[90] Sigl, 'Timing and climate forcing of volcanic eruptions'.

[91] For the repeated link between volcanic forcing and adverse weather reported in the Annals: F. Ludlow *et al.*, 'Medieval Irish chronicles reveal persistent volcanic forcing of severe winter cold events, 431–1649 CE', *Environmental Research Letters* 8:2

opportunistic use of, violence, which greatly exacerbated the effects of the bad weather. Thus, in 1116, as reported in the *Annals of Inisfallen*, 'Muirchertach Ua Briain invaded Laigin [Leinster]' and 'countless injuries were committed on that expedition: raids and conflicts, war and famine during that time'.[92] The combination of adverse weather, scarcity and warfare recurred in 1137 when, according to the *Annals of Tigernach*, 'Connacht, then, was laid waste from Assaroe to the Shannon and to Echtach [Slieve Aughty] of Munster, and the people themselves were driven into the west of Connacht'.[93] Hunger was, of course, a frequent consequence of military violence, since putting people to flight, driving off their cattle and torching the crops of the enemy were standard military ploys. In 1139, for example, the *Annals of the Four Masters* reported that the men of Meath destroyed the corn crops of the Ui-Briuin 'so that an insufferable famine prevailed amongst them [the men of Fermanagh] the year following'.[94]

Among scholars, the extent to which severe weather conditions have, in turn, historically promoted violence, and of what kind, in what contexts, and whether only rarely or more persistently, remains highly debated. Beyond the more obvious potential for conflict arising from scarcity induced resource competition, linkages may have been subtle and indirect. For instance, advantage may have been taken of crises to launch opportunistic attacks on weakened rivals or to question and challenge the fitness of dynasties to rule.[95] For medieval Ireland, the Annals do offer occasional explicit confirmation and explanation of such occurrences, not least the inclement weather, subsistence crisis and ensuing breakdown of order in 1050.[96] But in many instances they hold to the traditional annalistic style of presenting apparently disconnected events with little explanation of any causal connections.[97] Quantitative approaches that also make use of the independent evidence of palaeoclimatic proxies can here complement traditional readings of the annalistic evidence. An initial study (employing superposed epoch analyses) of the frequency and timing of a range of violent

(2013), L024035; Gao, 'Reconciling multiple ice-core volcanic histories'; McCormick, 'Volcanoes and the climate forcing of Carolingian Europe'.

92 Ludlow, 'Utility 2', 174.

93 Ludlow, 'Utility 2', 181.

94 Ludlow, 'Utility 2', 182–3.

95 A perceived link between the fertility of the land and quality of its ruler certainly existed in early medieval Ireland, persisting (if more ambiguously) into later centuries: Maxim Fomin, 'The early medieval Irish and Indic polities and the concepts of righteous ruler', *Cosmos* 15 (1999), 163–97; Lauren Baker, 'Mainstreaming morality'; Ludlow, 'Utility of the Irish Annals', vol. 1, 172, 190, 198–200, 217.

96 The links between adverse weather and socio-political conflict in medieval Ireland are further explored in: Ludlow and Travis, 'STEAM approaches to climate change'.

97 This tendency diminishes from the late-thirteenth century once hereditary professional historians in the employ of the Gaelic nobility took over recording of the Annals (McCarthy, *Irish Annals*, 245) and began to place the exploits of that nobility in a more narrative (but still annually arranged) structure.

events reported in the *Annals of Ulster* relative to the ice-core-based dates of 32 major volcanic eruptions is thus presented in Appendix 6. While there is much more to learn by examining the influence of a fuller spectrum of extreme events (e.g., droughts, wet weather), for different seasons and of different apparent severities, it is clear that violence is reported with increased frequency (sufficient to appear statistically non-random) in the aftermath of these eruptions.[98] It follows that other adverse weather events may have triggered similarly destructive behaviours, as evidenced in the years 1115–16 and 1137.

1150–1300—expansion, phase two

When Gerald of Wales visited Ireland in the 1180s he was impressed by the 'many woods' that yet remained, notwithstanding the rising rates of felling that had prevailed for the previous 30 to 40 years.[99] By the time of his visit, however, such high rates of felling were evidently becoming unsustainable and as the stock of oaks (represented in Fig. 5 by the annual number of dated oak samples) dwindled so felling and depletion rates began to subside. In parallel, references to church buildings in the Annals increase consistently into the twelfth century, but with a notable shift after *c*.1110 from construction mainly in oak (*dairthech*) to stone (*damliac* / *teampal*).[100] Although there are complexities to the interpretation of this information from the Annals, it is broadly consistent both with an expansion of building and, progressing from this, a depletion of oak. English demand for Irish oak was also a factor.[101] From an annual average of 226 oak samples in the 1150s, sample numbers decline to 93 in the 1200s, 55 in the 1250s and 29 in the 1300s. Although construction activity had to cope with a dwindling supply of oaks it was sustained until well into the thirteenth century by the first wave of new continental religious foundations and the great building boom—of fortifications, religious houses, churches, towns and settlements—that followed the English invasion of 1169–71 and the substantial influx of colonists to which

[98] Appendix 6 presents a series of superposed epoch analyses of the temporal relationship between 32 major explosive eruptions with an estimated volcanic stratospheric sulfur injection (VSSI) of at least 1.0 Tg (a measure reflecting climate forcing potential, and thus excluding nineteen eruptions discernable in the ice cores but of minimal climatic forcing potential and likely to introduce noise into the analyses) and levels of violence recorded in the *Annals of Ulster*. The effects were typically lagged, perhaps with production adversely affected the year following an eruption and recorded violence thus surging thereafter, though with some variability as to exact timing.

[99] Gerald of Wales, *History and topography of Ireland*, 34.

[100] Ó Carragáin, *Churches in early medieval Ireland*, 110–11.

[101] Tim Tatton-Brown, 'The roofs of Salisbury Cathedral', *Spire: Annual Report of the Friends of Salisbury Cathedral* 71 (2001), 18–23; Nicholas Vincent, 'Angevin Ireland', in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 185–221: 203–4; Margaret Murphy and Michael Potterton, *The Dublin region in the middle ages: settlement, land-use and economy* (Dublin, 2010), 375–6.

it gave rise.[102] That, no doubt, is why net depletion rates remained at a relatively high level until the 1200s. Only thereafter did the number of annually-dated samples shrink to single figures.

The evidence suggests that oaks had become so scarce by the mid-thirteenth century throughout the most closely settled parts of Munster and Leinster that datable oak samples from Leinster outside Dublin drop to single figures from 1239 and from 1250 to 1278 there are none at all from Munster. What appears to have been almost 200 years of more-or-less continuous felling had taken its toll. From this point, and as the country's population rose to what is likely to have been its medieval maximum of 1.25 to 1.5 million, Ireland's surviving timber resources appear to have been under considerable pressure.[103] Hereafter the Irish oak chronology becomes increasingly attenuated and, as samples from Munster and Leinster (outside Dublin) peter out, those from Ulster come increasingly to the fore. The smaller oak sample depth that this entails means that by the end of the century the oak-ring-width evidence and climate reconstructions derived from it are less robust, representative and stable than before. Fortunately, it is when the Irish oak record is thinnest that the English evidence of prices, wages, harvests and crop yields comes strongly on stream (Fig. 6).

For all that the English invasion of 1169–71 represents one of the deepest and most profound of all historical divides, environmentally the period that it punctuated is remarkable for its continuity. The defining feature of this era, from the 1050s until the early 1260s (when the Wolf Solar Minimum set in), was a consistently high level of solar irradiance (Fig. 1). Irradiance levels were especially elevated from the 1190s to the 1210s and again, and more impressively, from the 1230s to the 1250s, with an absolute peak between 1244 and 1253. It may be coincidence, but at this apogee of solar output in 1252 the *Annals of Loch Cé* (as also *of Connacht* and *of the Four Masters*) reported 'Great heat and drought in the summer of this year, so that people used to cross the Sinuinn

[102] Lydon, *The Lordship of Ireland in the middle ages*, 61, 91–3; Aubrey Gwynn and R. Neville Hadcock, *Medieval religious houses: Ireland* (London, 1970); Roger Stalley, 'Irish gothic and English fashion', in James Lydon (ed.), *The English in medieval Ireland: proceedings of the first joint meeting of the Royal Irish Academy and the British Academy, Dublin, 1882* (Dublin, 1984), 65–86: 68–77; Rachel Moss, 'Material culture' in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 469–97: 471–2.

[103] Campbell, 'Benchmarking medieval economic development', 927; Máire Ní Mhaonaigh, 'Perception and reality: Ireland *c*.980–1229', in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 131–56: 153. For the scarcity of woodland in the Dublin region by the thirteenth century and near exhaustion of local supplies of oak timbers: Murphy and Potterton, *Dublin region in the middle ages*, 357–76, 380–2. By the early fourteenth century the immediate environs of Drogheda seem to have been similarly denuded of woodland: J.A. Galloway, 'The economic hinterland of Drogheda in the later middle ages', in Vicky McAlister and Terry Barry (eds), *Space and settlement in medieval Ireland* (Dublin, 2015), 167–85: 179–80.

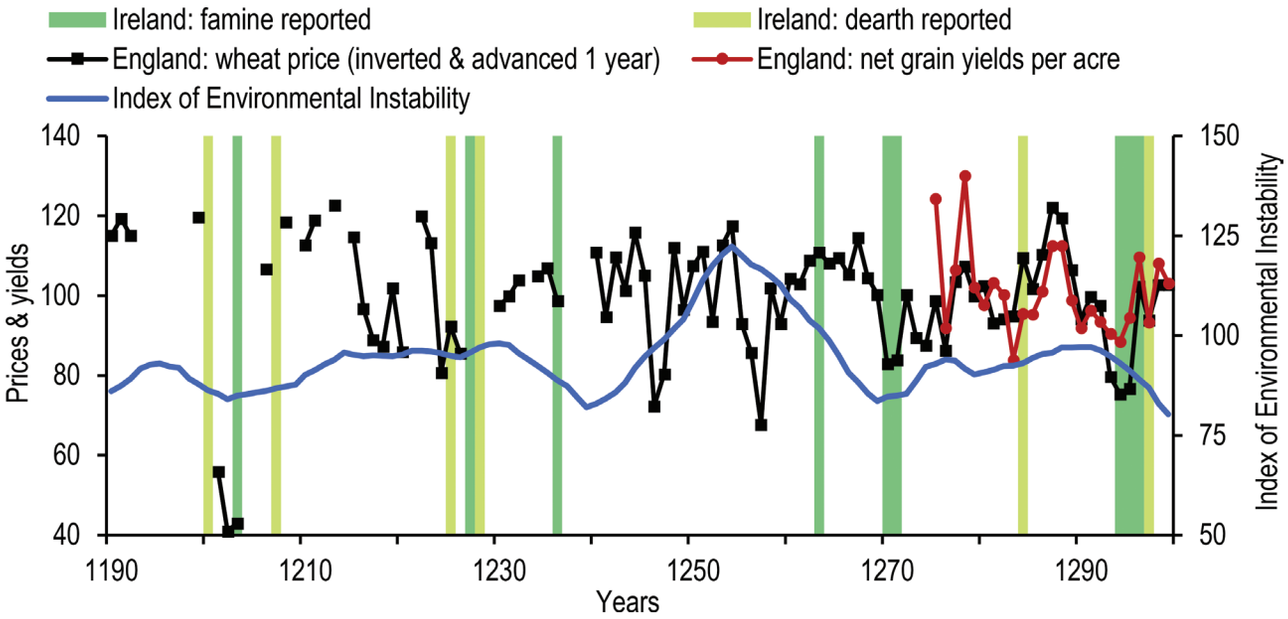

Fig. 6—Reports in the Gaelic and Anglo-Irish Annals of dearth and famine in Ireland, English wheat prices and net grain yields, and an Index of Environmental Instability, 1190–1300 CE.

Sources: *Dearth and famine in Ireland*: authors' own survey of Gaelic and Anglo-Irish Annals.

Wheat prices (*percentage of 25-year moving average centred, inverted and advanced one year*): Gregory Clark, 'English prices and wages 1209–1914', Global Price and Income History Group (Davis, 2009), www.iisg.nl/hpw/data.php#united. Accessed 15 Aug. 2015; extended and interpolated from 1166–1265 with prices from D.L. Farmer, 'Prices and wages', in H.E. Hallam (ed.), *The agrarian history of England and Wales, vol. 2: 1042–1350* (Cambridge, 1988), 716–817: 787–9, and additional prices for 1237–62 from the manorial accounts of Froyle, Hampshire: British Library, Add. Charters 17, 459–78, 13,338–9; Hampshire Record Office, Winchester, 123M88W/1.

Net grain yields per acre (deviations from trend in net wheat-barley-oats [*W-B-O*] *yields, averaged using the weighted ratio 2:1:1)*: B.M.S. Campbell and Cormac Ó Gráda, 'Harvest shortfalls, grain prices, and famines in pre-industrial England', *Journal of Economic History* 71:4 (2011), 859–86: 866; B.M.S. Campbell, *Three centuries of English crop yields, 1211–1491* (Belfast, 2007), www.cropyields.ac.uk.

Index of Environmental Instability: Appendix 5.

[Shannon] without wetting their feet; and the wheat was reaped twenty nights before Lammas [1 August], and all the corn was reaped at that time; and the trees were burning from the sun'.[104] The following year the same Annals celebrated 'the

[104] Ludlow, 'Utility 2', 225–6. The *Annals of Ulster*, followed closely by the *Annals of Inisfallen*, simply note 'A hot summer in this year'. The Welsh *Brut y Tywysogyon* (pp. 243–5) is less laconic: 'the heat of the sun was so great that the whole earth dried therewith, so that hardly any crops grew on the trees or in the fields and neither sea nor river fish were found. And that summer was called the Hot Summer. And at the close of that autumn the rains were so great that the floods covered the face of the earth, so that the extreme dryness of the earth could not absorb the waters, and the rivers flooded so that

best year that had ever come for nuts, and the produce of the earth, and of cattle, and of trees and herbs'.[105] Then, the very next year, the *Annals of Boyle* recorded another possible dividend of the fine weather: 'peace in Ireland'.[106] Abundance, it would seem, suppressed the propensity to violence. Unfortunately, such nominal tranquility was not to last.

Incoming solar irradiance was, of course, the energy source that powered the world's ocean currents, determined pressure gradients and shaped and directed patterns of atmospheric circulation. In the case of Ireland and Britain that meant the prevalence of a strongly positive NAO. In a recent reconstruction, the NAO was positive for two out of three years from 1150 to 1300, was never weaker than -1.0 but on 22 occasions was stronger than +1.0 and in 1252 reached an absolute extreme of +2.5 (Appendix 3).[107] While this climate regime prevailed, a westerly Atlantic airstream powerfully influenced meteorological conditions in Ireland and precipitation, especially in winter, was rarely deficient, credibly prompting Gerald of Wales's comments about the windiness and wetness of the Irish weather.[108]

Warm and dry summers were not unknown but only in 1252 and 1263 did Ireland's annalists explicitly note drought and heat as problems.[109] The aridity of 1252, when 'people crossed the principal rivers of Ireland with dry feet', was therefore remarkable.[110] The opposite was more commonly the case and, on the evidence of the climate reconstructions, the wettest growing seasons were

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the bridges and the mills and the houses close to the rivers were shattered, and the trees and the orchards were swept away, and many other losses were caused'. For England, chronicles such as that of Bury St. Edmund's furnish report of '…an exceptionally hot summer [that] killed many people, and alarming thunder was heard on the day after the Assumption of the Blessed Virgin [16 August]' (Antonia Gransden (ed.), *The chronicle of Bury St Edmunds, 1212–1301* (London, 1964): 17–18); also Kathleen Pribyl and R.C. Cornes, 'Droughts in medieval and early modern England, part 1: the evidence', *Weather* 75:6 (2020), 168–72: 168. On the Scottish border, the Lanercost Chronicle makes similar reference to the exceptional heat: Richard Oram, '"The worst disaster suffered by the people of Scotland in recorded history": climate change, dearth and pathogens in the long 14th century', *Proceedings of the Society of Antiquaries of Scotland* 144 (2014), 223–44: 226. The OWDA clearly registers severe drought of unusual extent across much of northern, southern, western and eastern Europe for 1252, with only parts of central Scotland and north-west Ulster (alone in Britain and Ireland) apparently spared the worst: Cook, 'Old World megadroughts'. For the direct and indirect socioeconomic and health impacts of the 1252 drought and others: Kathleen Pribyl, 'A survey of the impact of summer droughts in southern and eastern England, 1200–1700', *Climate of the Past* 16 (2020), 1027–41.

[105] Ludlow, 'Utility 2', 226.

[106] Ludlow, 'Utility 2', 227.

[107] Ortega, 'Model-tested North Atlantic Oscillation reconstruction'.

[108] Above, p. 160; Gerald of Wales, *History and topography of Ireland*, 34–5.

[109] 1263 (*Annals of Clonmacnoise* (a.k.a. *Mageoghagan's Book*), also *of Ulster*, *of Loch Cé* and *of Connacht*): 'There was a great drought this year in the earth and a very hot summer': Ludlow, 'Utility 2', 235.

[110] Ludlow, 'Utility 2', 225–6.

in 1153, 1156, 1159, 1229 (the year of a notable tropical eruption),[111] 1255 and 1292–3 (Appendix 2). In 1158, the *Annals of the Four Masters* reported 'great rain in the summer' and, more seriously, in 1236 the same Annals, along with those *of Loch Cé* and *of Connacht*, complained of 'heavy rains, harsh weather, and much war'.[112] The occasional cold and snowy winters, when Arctic high pressure presumably kept the normally mild westerly Atlantic airstream at bay, also attracted comment, especially when, as in 1156, 1178, 1234 and 1251, lakes and rivers froze over and were passable on foot.[113] These extreme once-in-a-generation events were no doubt recorded, remembered and talked about precisely because they were so rare.[114] They were particularly hazardous to Gaelic

[111] Sigl, 'Timing and climate forcing of volcanic eruptions' place this event in 1230, while Toohey and Sigl, 'Volcanic stratospheric sulfur injections' place it in 1229, adjusting for estimated sulphate travel time to the polar ice-sheets.

[112] Ludlow, 'Utility 2', 191, 217–18.

[113] 1156 (*Annals of the Four Masters*, also *of Tigernach*): 'There was great snow and intense frost in the winter of this year, so that the lakes and rivers of Ireland were frozen over. Such was the greatness of the frost, that Ruaidhri Ua Concobhair drew his ships and boats on the ice from Blean-Gaille [Galey, an island on Lough Ree] to Rinn-duin [Rindoon or Rindown, Co. Roscommon]. Most of the birds of Ireland perished on account of the greatness of the snow and the frost'. 1178 (*Annals of Tigernach*): 'A great frost, so that for the space of a month one went on foot on the lakes of Ireland'. 1234 (*Annals of Connacht*, also *of Ulster*, *of Loch Cé* and *of Boyle*): 'Heavy snow fell between the two Christmases, followed by such a frost that men and laden horses walked on the great lakes and rivers of Ireland'. 1251 (*Annals of Loch Cé*, also *of Connacht*): 'Great frost in the early winter, so that the lakes, and the bogs, and the waters were all frozen'. Ludlow, 'Utility 2', 190–1, 195–6, 215–16, 224–5.

[114] In 1165 the *Annals of Tigernach* reported 'A great snow in this year, so that it was a labour for men and for cattle to go about in it' (Ludlow, 'Utility 2', 191), but make no mention of frozen or load-bearing ice, animal mortality, or the localities affected. More intriguing is the report in 1179 (*Annals of Ulster*, also *of Inisfallen*, *of Boyle* and *Mac Carthaigh's Book*) that 'The snow of the destruction [fell] this year': Ludlow, 'Utility 2', 196. This curious entry and its companions in the other Annals—variously translated as noxious, venomous or poisonous from effectively the same Irish phrase, '*sneachta na n-emhi*', reproducing here the text of the *Annals of Inisfallen*, from which only the *Annals of Ulster* depart with *sneachta na mure*—may reflect snowfall laced with poisonous volcanic acids or indeed volcanic ash. A comparable entry is also found in the *Annals of Connacht* (also *of Loch Cé*) in 1245: 'Virulent snow fell on the eve of St Nicholas [6 December], and folk who walked in it lost their heels and toes. The snow lay until Great Christmas [25 December]': Ludlow, 'Utility 2', 223. On both occasions fallout from eruptions in *c*.1179 and 1245 by the major Icelandic volcano of Katla may have been responsible: Thorvaldur Thordarson and Guðrún Larsen, 'Volcanism in Iceland in historical time: volcano types, eruption styles and eruptive history', *Journal of Geodynamics*, 43 (2007), 118–52: 134. For the potential impact of volcanic tephra on Irish vegetation in the early medieval period: V.A. Hall, 'Assessing the impact of Icelandic volcanism on vegetation systems in the North of Ireland in the fifth and sixth millennia BC', *The Holocene* 13 (2003), 131–8. For a suggestion that an eruption of Hekla, Iceland, may lie behind a further event in the Annals in 1224 (quoted in Ludlow, 'Utility 2', 208–11) in which apparently toxic materials were deposited: M.G.L. Baillie, *A slice through time: dendrochronology and precision dating* (London, 1995), 102.

pastoralists who relied upon grass rather than stored fodder to see their livestock through the winter.[115]

Plainly, even though geographical and temporal coverage by the Annals is exceptionally good at this time (Figs 2 and 3), the weather events reported by them must be considered an incomplete record of those extremes that occurred in this period.[116] Further, the stochastic nature of the occurrence of those events means that, even with a complete record of, say, all extremes passing a minimum threshold of severity or spatial extent, trends in their occurrence need not perfectly follow trends in background average climatic conditions.[117] Yet some degree of correspondence between trends in averages and extremes can still plausibly be expected, and the annalistic evidence is broadly consistent with one of the most striking features of this climatic era, namely, the relatively muted scale of annual weather variations identifiable from available palaeoclimatic proxies. Across these years the Index of Environmental Instability based on the variance of six independent environmental variables is persistently subdued and in the 1160s sank to a historical low (Fig. 1). The one episode of notably heightened instability was in the 1250s and 1260s, when powerful volcanic forcing came hard on the heels of conspicuously strong solar forcing and the NAO was close to maximum strength (Appendix 3).[118]

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[115] Ó Corráin, 'Ireland *c.*800: aspects of society', 571–2; A. Keleman *et al.*, 'Indigenous agriculture and the politics of knowledge', in Paul Sillitoe (ed.), *Indigenous knowledge: enhancing its contribution to natural resources management* (Cambridge, 2017), 203–17: 206–8.

[116] Ludlow, 'Assessing non-climatic influences'; Ludlow, 'Utility of the Irish Annals', vol. 1, 231–82.

[117] If average temperatures fall in a given period it is more likely, but not guaranteed, that the incidence of extremes of cold will also increase. The probability of this depends upon how the shape of the distribution of temperatures (or precipitation, windiness, etc.) has changed (e.g., even if the average shifts lower, the incidence of extreme cold—defined as temperatures falling below some threshold—may not increase if temperatures also range more narrowly about that average).

[118] The explosive eruption of the Samalas volcano, Indonesia, in spring/summer 1257 was the main forcing event (VSSI of 59.42 Tg: Toohey and Sigl, 'Volcanic stratospheric sulfur injections'), but in its wake a minor extratropical northern-hemisphere eruption in 1260 (VSSI of 1.05 Tg: Toohey and Sigl, 'Volcanic stratospheric sulfur injections') may have helped produce the reduced temperatures and depressed southern English grain harvests that followed in 1261–2: F. Lavigne *et al.*, 'Source of the great AD 1257 mystery eruption unveiled, Samalas volcano, Rinjani volcanic complex, Indonesia', *Proceedings of the National Academy of Sciences* 110:42 (2013), 16742–7; Campbell, 'Global climates'; Sigl, 'Timing and climate forcing of volcanic eruptions'; S. Guillet *et al.*, 'Climate response to the Samalas volcanic eruption in 1257 revealed by proxy records', *Nature Geoscience* 10 (2017), 123–8; F. Ludlow, 'Volcanology: chronicling a medieval eruption', *Nature Geoscience* 10 (2017), 77–8. Note that a small northern hemispheric eruption placed in 1262 by Sigl and others, is now considered southern hemispheric by Toohey and Sigl. On issues of dating concerning this complex conjuncture of events: Martin Bauch, 'Chronology and impact of a global moment in the thirteenth century: the Samalas eruption revisited', in Andrea Kiss and Kathleen Pribyl (eds), *The dance of*

While Scotland experienced significant weather-related problems at this time and these years brought some serious harvest problems to England, and in 1258 a much commented upon flood of famine refugees to London,[119] the Irish annalists are silent on any extreme weather experienced at this time in Ireland and rather ambiguous as to any potentially related societal stress.[120]

High levels of volcanic activity, with half-a-dozen major tropical eruptions between 1170 and 1300—including the largest of them all in 1257—and almost as many mid- to high-latitude northern hemisphere eruptions (Fig. 1), ensured that the otherwise fairly stable climatic conditions were interrupted by multiple short-term climate anomalies. This conjunction of bouts of strong volcanic forcing with strong background solar forcing likely overrode more localised and regionally specific expressions of climate variance and helps to explain why correlations between the ring widths of Irish and English oaks are mainly strongly positive from the 1170s until the 1260s (Fig. 4). As shown in Fig. 6, reports in the Annals of poor harvests, dearth and, worst of all, famine, commonly coincided with the high-price years that followed poor harvests in England. There were, of course, exceptions, as most conspicuously in 1246–7 and (as discussed) 1257 when there appears to have been no clear counterpart in Ireland to the stressful conditions experienced in England, but this may reflect the selective nature of what the Irish annalists recorded (or later copied from older texts), especially when significant religious, political and military events claimed their attention.

It should not be forgotten that the Annals were primarily concerned with the Gaelic Irish regions of the midlands, north and west (Fig. 3), whose stronger focus upon pastoral agriculture proved less vulnerable to the types of weather extremes that impacted most negatively upon the more arable-focused economies of both the English Lordship of Ireland and England.[121] Frustratingly, the more populous grain-growing lands of the English Lordship, where weather-induced harvest failures may have had some of their greatest impacts, are more poorly served by surviving chronicles. Thus, without the lone testimonies of the Anglo-Irish *Annals of Ireland, A.D. 1162–1370* and Grace's *Annales Hiberniae*

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death in late medieval and Renaissance Europe: environmental stress, mortality and social response (London, 2019), 214–32.

[119] In the Scottish Cairngorms the summers of 1256 and 1261 were significantly cold and colder than that of 1258: Rydval, '800 years' (the authors are grateful to Rob Wilson for making the detailed temperature chronology available); Oram, 'Worst disaster', 225, 227; Campbell, 'Global climates'.

[120] Of possible Irish impacts, the *Annals of Inisfallen* report for 1259: 'A common cough this year affecting human beings and horses, which was called *galar na placodi*': Ludlow, 'Utility 2', 234–5; Martin Bauch, 'Chronology and impact of a global moment in the thirteenth century'. For 1260, the *Annals of Inisfallen* also report: 'Much sickness this year and death of noble folk', and for 1263 (perhaps too distant in time from Samalas in 1257) other Annals variously note drought, plague and famine: Ludlow, 'Utility 2', 234–5.

[121] Keleman, 'Indigenous agriculture', 206–8.

there would be little explicit to indicate that eastern Ireland, like much of neighbouring England, experienced 'great dearth and pestilence' for three consecutive years from 1294 to 1296.[122]

If the testimony of the Annals is taken at face value, crisis years tended to come in clusters with often quite long intervals in between. The opening years of the thirteenth century are a case in point. Problems began in 1200 (the year of a notable extratropical northern hemispheric volcanic eruption),[123] described in the *Annals of Loch Cé* as a 'cold, foodless year, the equal of which no man witnessed in that age'.[124] The *Annals of Inisfallen* followed this for 1201, noting that 'The greater part of the corn crop of Desmumu [Desmond territory, southern Munster] was laid waste…', and by 1203 difficulties had escalated to the point where the *Annals of Loch Cé* recorded 'great famine [*Gorta mhór*] in all Erinn generally in this year'.[125] More explicitly, the *Annals of Clonmacnoise* stated 'there was great scarcity of victuals throughout the whole kingdom of Ireland this year, [such] that infinite numbers of *the meaner sort* [emphasis added] perished for want…'.[126] Excess mortality, especially among the poorer classes, is a hallmark of genuine famine.[127] England, too, was in trouble. Following storms

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[122] 'Annals of Ireland, A.D. 1162–1370 [MS Laud, No. 526—Bodleian Library Oxford]', in J.T. Gilbert (ed.), *Chartularies of St Mary's Abbey, Dublin* (2 vols, London, 1884–6, reprinted Cambridge, 2012), vol. 2, 303–98: 323; Richard Butler (ed.), *Jacobi Grace, Kilkenniensis, Annales Hiberniae* (Dublin, 1842), cited in M.C. Lyons, 'Weather, famine, pestilence and plague in Ireland, 900–1500' in E.M. Crawford (ed.), *Famine: the Irish experience 900–1900* (Edinburgh, 1989), 31–74: 61; E.M. Crawford (ed.), 'William Wilde's table of Irish famines 900–1850', in Crawford, *Famine: the Irish experience*, 1–30: 5. The closest the Irish Annals come here is a 1296 report of snow and bad weather (but without any associated societal stresses), and a report for 1297 of inclement weather, cattle murrain and heightened human mortality: Ludlow, 'Utility 2', 239–40.

[123] Sigl, 'Timing and climate forcing of volcanic eruptions'; Toohey and Sigl, 'Volcanic stratospheric sulfur injections' (3.29 Tg VSSI).

[124] Ludlow, 'Utility 2', 201–3. Intense conflict and a near scorched earth policy undoubtedly contributed to the severity of this year, such that 'never before was there inflicted on the Connachtmen any punishment of famine, nakedness, and plundering like this punishment' (*Annals of Loch Cé*, also *of Boyle*). This would not be the last time such devastation arose from the interplay between Gaelic and English lords, climate and landscape in thirteenth-century Connacht: Thomas Finan, *Landscape and history on the medieval Irish frontier: the king's cantreds in the thirteenth century* (Turnhout, 2016).

[125] Ludlow, 'Utility 2', 205.

[126] The *Annals of Loch Cé* note in full that 'Great famine [prevailed] in all Erinn generally in this year, so that the clergy used to eat meat in Lent', invoking an image for contemporaries of a situation so dire that religious observances were abandoned and valuable cattle were slaughtered. *Mac Carthaigh's Book* also opines that 1203 experienced 'A windy, wet summer, with famine and wars': Ludlow, 'Utility 2', 205. The summer of the previous year, 1202, had been conspicuously cold in the northern Cairngorms of Scotland: Rydval, '800 years'.

[127] Symptoms of famine include 'rising prices, food riots, an increase in crimes against property, *a significant number of actual or imminent deaths from starvation* [emphasis

and unseasonable weather in 1201 and 1202, grain and livestock prices soared in 1203 and remained very high the following year (Fig. 6), when many in Ireland were succumbing to 'severe pestilence'.[128] A hard winter followed in 1205 and then serious problems returned in 1206, when the *Annals of Ulster* reported a 'great destruction on people and cattle in this year'.[129] On and off, this was a crisis of seven years duration and it undoubtedly left Irish society diminished in size and vigour.

The next clutch of difficult years began in 1219, which the *Annals of Clonmacnoise* reported to have been 'wet, windy, and boisterous, with great destruction of corn'.[130] Persistently disturbed weather conditions then followed from 1222–5, perhaps as a part consequence of the extratropical northern-hemisphere eruption of Hekla in Iceland in *c.*1222.[131] For 1222 the Annals report a great storm that caused widespread damage to buildings, forests and ships, followed in 1223 by a 'great wind on the day after the festival of Matthew [21 September], which injured all the oats of Erinn that it found standing', while in 1224 'the corn remained unreaped, until the festival of St. Brigid [1 February], when the ploughing was going on, in consequence of the war and inclement weather'.[132] English chroniclers reported stormy weather and a bad harvest in 1225 and the same year the harvest in Ireland was late and the *Annals of Loch Cé* and

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added], a rise in temporary migration, and frequently the fear and emergence of famine-induced infectious disease': Cormac Ó Gráda, *Famine: a short history* (Princeton, 2009), 7.

[128] Britton, 'Meteorological chronology', 73–9; C.R. Cheney, 'Levies on the English clergy for the poor and for the king, 1203', *English Historical Review* 96 (1981), 577–82: 580–1; D.L. Farmer, 'Some price fluctuations in Angevin England', *Economic History Review* 9 (1956), 34–43. 1204 (*Annals of Inisfallen*): 'A very severe pestilence in the above year, and houses were emptied in Mide, Laigin, Áth Cliath, Cell Dara, Ferna Maedóc, Cell Chainnig, and in Maethal Brócáin in the Déisi, and it reached Ailén Maíl Anfaid and killed a large number of the seniors of the community, including the abbot Ua Lígda': https://celt.ucc.ie//published/T100004/index.html (AI1204.2).

[129] For the 1205 hard winter, the *Annals of Loch Cé* uniquely report: 'Great frost and snow from the kalends of January [1 January] to the festival of Patrick [17 March] in this year'. The report cited in the main text for 1206 is given effectively verbatim in the *Annals of Ulster* and *of Loch Cé*: Ludlow, 'Utility 2', 206. Note that the Icelandic volcano Hekla erupted in 1206, leaving no clear sulphate signature in the Greenland ice but with this volcano's joint-second greatest tephra release by volume in the second millennium CE: Thordarson and Larsen, 'Volcanism in Iceland in historical time', 141.

[130] For 1219 the *Annals of Loch Cé* also stated that '…Droichet-atha [Drogheda, Co. Louth] was carried away by the flood': Ludlow, 'Utility 2', 206–7.

[131] Thordarson and Larsen, 'Volcanism in Iceland in historical time', 141. Given its proximity to Greenland, Hekla may be responsible for the small sulphate signal in Greenland in 1222 (VSSI of 0.87 Tg: Toohey and Sigl, 'Volcanic stratospheric sulfur injections').

[132] Ludlow, 'Utility 2', 207–9. The storm of 1222 is documented in the *Annals of Ulster, of Loch Cé*, and *Mac Carthaigh's Book*, while that of 1223 is found in the *Annals of Loch Cé* and the adverse conditions of 1224 are reported in the *Annals of the Four Masters*.

of Ulster reported a 'great destruction of people'.[133] Two years later, in 1227, the situation had deteriorated further: the *Annals of Connacht*, *of Boyle* and *of Loch Cé* all reported upon the 'Great famine [*Gorta mór*] throughout Ireland this year, and much sickness and death among men from various causes: cold, famine and every kind of disease'.[134] The next year, 1228, brought little respite: European summer temperatures dropped sharply and in Connacht war again compounded the adverse effects of the weather.[135] Ongoing warfare prolonged this miserable state of affairs into the following years as the bad weather continued and in one way or another affected the whole of Britain and Ireland. Thus, in 1232, following renewed volcanic forcing in *c.*1229/30 (this time from a substantial tropical eruption), the Scottish Cairngorms experienced the coldest summer of the thirteenth century and English chroniclers reported, first, a summer with too little rain and, then, a summer with too much.[136] Finally, in 1236, the *Four Masters*

[133] 1225 (*Annals of Loch Cé*, also *of Ulster*, *of Connacht*, *of the Four Masters*, *of Boyle* and *Mac Carthaigh's Book*): 'The corn was reaped immediately after the festival of [St] Brigid [1 February]; and the ploughing was going on at the same time': Ludlow, 'Utility 2', 211–12. The *Annals of Connacht* and *of the Four Masters* are explicit in their accounts of the intersection of conflict, climate, disease and hunger in Connacht at this time: 'After the plunderings and slaughter of men and beasts and the exposure of the inhabitants to cold and hunger, a severe attack of sickness came upon the countryside, a kind of fever, which emptied towns of every living soul; and though some who took this sickness did recover, they were but a few' (*Annals of Connacht*, with a shortened notice of disease in the *Annals of Boyle*); 'Woeful was the misfortune, which God permitted to fall upon the best province in Ireland at that time! For the young warriors did not spare each other, but preyed and plundered each other to the utmost of their power. Women and children, the feeble, and the lowly poor, perished by cold and famine in this war!' (*Annals of the Four Masters*): Ludlow, 'Utility 2', 211–12.

[134] Ludlow, 'Utility 2', 212–13. The summer of 1227 was exceptionally cold in the Scottish Cairngorms: Rydval, '800 years'.

[135] 1228 (*Annals of the Four Masters*, also *of Ulster*, *of Loch Cé* and *of Connacht*): 'An intolerable dearth prevailed in Connaught, in consequence of the war of the sons of Roderic. They plundered churches and territories; they banished its clergy and ollaves into foreign and remote countries, and others of them perished of cold and famine': Ludlow, 'Utility 2', 213.

[136] This (VSSI of 23.78 Tg) tropical eruption is dated 1229 by Toohey and Sigl, 'Volcanic stratospheric sulfur injections', and 1230 by Sigl, 'Timing and climate forcing of volcanic eruptions'. 1230 (*Annals of Loch Cé*, also *of Connacht*): '…the Foreigners sent out great predatory bands as far as Sliabh-an-iarainn [Sliabh Anierin, Co. Leitrim], and subjected multitudes to cold and hunger on this occasion. And women and children were killed; and all that were not killed were stripped; and they carried off great, fruitful preys to the camp of the Foreigners'. 1234 (*Annals of Ulster*, also *of Loch Cé*, *of Connacht* and *of Boyle*): 'Great snow between the two Nativities in that year [25 December to 6 January]. Great frost thereafter, so that persons and horses went under burdens upon the rivers and lakes of Ireland'. 1235 (*Annals of Loch Cé*): 'The Foreigners afterwards left Connacht without food, clothes, or cattle; and they did not carry off with them either pledges or hostages on this journey; and they left neither peace, nor quietness, nor tranquillity, nor happiness in the country; but the Gaeidhel themselves were robbing and killing one

annalist recorded 'Heavy rains, harsh weather, and much war prevailed in this year'.[137] This is the last such report in the Annals for over 25 years.

Ireland was, however, revisited by serious harvest-related crises on three further occasions before the thirteenth century ended. The first was in 1263, when, following a summer of heat and drought, the *Annals of Ulster* reported 'great destruction on [*sic*] people this year by plague and by famine'.[138] Then, in 1270, 'great, unbearable famine in all Ireland', 'great famine and scarcity in all Erinn' and 'hunger and great destitution throughout Ireland' were reported, respectively, by the *Annals of Ulster*, *of Loch Cé* and *of Connacht*.[139] According to the *Annals of Inisfallen* the year had begun with heavy snow, while a severe winter followed by a wet spring is reported by English chroniclers.[140] This was the first year of a back-to-back crisis. It was followed in 1271 by 'very bad weather in that year, and general warfare between the foreigners [English] and Gaedil of Ireland; and there was a great famine in the same year so that *multitudes of poor people died of cold and hunger and the rich suffered hardship* [emphasis added]' (*Annals of Inisfallen*).[141] Note that in this second year of the crisis both rich and poor were adversely affected, and that among the poorer classes many were now reportedly paying the ultimate penalty of death. In Scotland, too (but dated 1272 by the fifteenth-century chronicler Walter Bower), 'many people fell ill and many animals died', while in England the continuing wet weather depressed grain yields and drove up prices (Fig. 6).[142] In Ireland, where the language of

another regarding the residue which the Foreigners left in it on this occasion': Ludlow, 'Utility 2', 213–14. Rydval, '800 years'; Britton, 'Meteorological chronology', 88–90.

[137] Ludlow, 'Utility 2', 217–18. The *Annals of Connacht* (with a close duplicate in the *Annals of Loch Cé*) also summarises the civil-war-like conditions prevailing during the preceding years: 'This was a year of wet and storm and war, of hunger and scarcity of food and clothing; armed bands and evil-doers without reverence for church or privilege, being excommunicated by the hands of bishops; the reverend clerics of the Catholic Church in fear and dread every day and night; frequent routs and escapings from Gael and Gall to the churches and churches used as dormitories, this year and for the space of 12 years ever since O Neill's war; Galls and Gaels plundering by turns; no lordship or government, but Connacht lying open for the Galls to ruin whenever they came into it, and its King and eligible princes plundering and violating church and countryside in their wake'.

[138] Ludlow, 'Utility 2', 235.

[139] Ludlow, 'Utility 2', 236. The underlying Irish and Latin identifies these three entries as duplicates of a lost original.

[140] 1270: 'A heavy fall of snow about the Epiphany [6 January]': Ludlow, 'Utility 2', 236. Britton, 'Meteorological chronology', 114–15. There had been a VSSI 3.13 (Tg) southern-hemisphere eruption in 1269, but further work is required to assess the impacts of such events on northern-hemisphere climates: Toohey and Sigl, 'Volcanic stratospheric sulfur injections'.

[141] Ludlow, 'Utility 2', 236. For the spur the famine gave the Wicklow Irish to raiding of the archbishop of Dublin's neighbouring lowland manors: James Lydon, 'A land of war' in Cosgrove (ed.), *New history of Ireland*, *vol. 2*, 240–74: 256–7; Katherine Simms, 'The political recovery of Gaelic Ireland', in Smith, (ed.), *Cambridge history of Ireland, vol. 1*, 272–99: 275.

[142] Oram, 'Worst disaster', 225.

the annalists implies that the situation had become particularly grave, the weather-induced food scarcity was greatly compounded by the outbreak of 'general warfare between the foreigners and Gaedil of Ireland' (*Annals of Inisfallen*).[143] This was an increasingly familiar pattern.

Nevertheless, it was the last harvest crisis of the thirteenth century that was probably the most punitive, at least within the territories of the English Lordship. Here the Anglo-Irish Annals attest that for three consecutive years from 1294 to 1296 the weather ruined crops 'resulting in great dearth' and 'many deaths from hunger'.[144] Wheat prices in the Dublin region in 1294–5 and 1295–6 rose to 80 per cent above the recorded average for 1280–1300 and the records of Christ Church Cathedral claimed that 'people ate the corpses of those who had been hanged at the crossroads'.[145] Friar John Clyn of Kilkenny refers to 'the greatest scarcity' and many dying of hunger during these years and, according to the *Annals of Ireland, A.D. 1162–1370*, 'pestilence' contributed to the death toll.[146] James Lydon believes that the dearth drove the Gaelic Irish of the Leinster mountains into rebellion.[147] Further problems were created by the bitter feud that broke out between the earls of Kildare and Ulster.[148] These were also crisis years in England, when, on both sides of the Irish Sea, depressed temperatures and elevated rainfall resulted in a succession of inferior harvests.[149] Thus, the six consecutive years 1290–95 stand out as persistently wet in the OWDA spring–summer soil-moisture reconstruction for Ireland (Appendix 2), more so than in dearth-bound England, with 1292 the wettest in more than a hundred years. These were cold years as well, with a significant drop in summer temperatures in the northern Cairngorms of Scotland in 1294–6 and the European summer of 1294 the coldest since 1127.[150] The Munster-focused *Annals of Inisfallen*, as previously noted, reported that the winter of 1296 brought 'heavy snow and bad weather', followed in 1297 by 'very stormy weather…with wind, snow, and lightning, and a great murrain of cattle and loss of life also'.[151] Evidently the cooling effects

[143] Ludlow, 'Utility 2', 236. For 1271, Grace's *Annales Hiberniae* recount 'Pestilence, famine, and the sword in Ireland, and chiefly in Meath': Richard Butler (ed.), *Jacobi Grace, Kilkenniensis, Annales Hiberniae* (Dublin, 1842), 37.

[144] 'Annals of Ireland', 323; 'William Wilde's table of Irish famines', 5; Lyons, 'Weather, famine, pestilence and plague', 61.

[145] Murphy and Potterton, *Dublin region in the middle ages*, 478–9; cannibalism is cited in Maria Kelly, *The great dying: the Black Death in Dublin* (Stroud, 2003), 41.

[146] Bernadette Williams (ed. and trans.) *The Annals of Ireland by Friar John Clyn* (Dublin, 2007), 154–5; 'Annals of Ireland', 323.

[147] Lydon, 'A land of war', 260–1.

[148] Seán Duffy, *Ireland in the middle ages* (Basingstoke, 1997), 127–8.

[149] Britton, 'Meteorological chronology', 127–9; Campbell, *Great Transition*, 201–2; P.R. Schofield, 'Dearth, debt and the local land market in a late thirteenth-century village community', *Agricultural History Review* 45:1 (1997), 1–17.

[150] Rydval, '800 years'; Luterbacher, 'European summer temperatures since Roman times', (data: www.ncdc.noaa.gov/paleo/study/19600; accessed 19/08/2016).

[151] Ludlow, 'Utility 2', 240.

of the Wolf Solar Minimum were beginning to bite, reinforced at their nadir by the climate-forcing from major tropical eruptions (VSSI of 11.53 and 15.06 Tg, respectively) in 1275 and 1285 (Fig. 1).[152] Such powerful environmental forces challenged agrarian societies almost everywhere: Britain and Ireland were far from unique in the difficulties experienced at this time.[153]

By the 1290s the relatively stable and benign weather that had prevailed for so much of the previous 150 years had passed. The Medieval Solar Maximum that had helped to sustain it had ended. Under the influence of the Wolf Solar Minimum and reinforced by powerful volcanic forcing and consequential Arctic sea-ice formation,[154] global temperatures were cooling and long-established tendencies of atmospheric circulation were beginning to unravel.[155] The climate system was losing its resilience, as was Irish society, most particularly in areas of the English Lordship in Ireland. Whereas the periodic crises of the first half of the thirteenth century had been characteristically followed by a return to the *status quo ante*, that was no longer the case. One symptom of the change is the progressive weakening of the correlation between the ring widths of Irish and English oaks over the course of the second half of the thirteenth century (Fig. 4). Another is the clear testimony of the chroniclers that these later subsistence crises and famines, in 1270–1 and 1294–6, resulted in significant fatalities. War and disease and the heavy fiscal and military demands of an increasingly belligerent crown upon its Irish Lordship were also sapping society of its ability to recover,[156] and doing so as Europe's once vibrant commercial economy entered a prolonged and deepening recession.[157] The institutions

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[152] Sigl, 'Timing and climate forcing of volcanic eruptions'; Toohey and Sigl, 'Volcanic stratospheric sulfur injections' (whose dating, in both cases one year earlier than that of Sigl, is followed here); Ludlow, 'Medieval Irish chronicles'. The Annals record a sequence of inclement and often cold conditions with major societal stresses during the confluence of these forcings from 1279 through the 1280s, including heavy snow and mass mortality of domestic animals in 1279 and 1280, mass human mortality and implied scarcity in 1281, snow, frost, windstorms and agricultural difficulties in 1282, conflict-driven migration and famine in Munster in 1283, unspecific but severe weather in 1284, violent wind in 1285 and scarcity of corn with high prices also in 1285, alongside mass cattle mortality from disease: Ludlow, 'Utility 2', 237–9.

[153] Campbell, *Great Transition*, 250–4.

[154] Miller, 'Abrupt onset of the Little Ice Age'.

[155] Campbell, *Great Transition*, 198–208.

[156] Mark Hennessy, 'Making Ireland English in the thirteenth century: the evidence of the Irish lay subsidy of 1292', in P.J. Duffy and W. Nolan (eds), *At the anvil: essays in honour of William J. Smyth* (Dublin, 2012), 81–91; Campbell, 'Boom to bust'.

[157] Campbell, *Great Transition*, 267–77; Ljungqvist, 'Linking European building activity with plague history', 85–6; Buringh, 'Church building and the economy'. Irish government and customs revenues shrank continuously from their peak in the early 1280s, with a particularly marked fall following the Scottish invasion of 1315–18: Campbell, 'Benchmarking medieval economic development', 896–7; Lydon, *Lordship of Ireland*, 131–8; Duffy, *Ireland in the middle ages*, 128–33.

and resources required to counter scarcity and the lawlessness that it could nurture were being weakened and depleted at the very time the need for them was growing. The weather was on the change and so, too, was society.

1300–1340s: resource scarcity

Frustratingly, the Irish oak chronology becomes perilously thin during the first half of the fourteenth century (Fig. 5A), rendering it less robust and less representative of growing conditions across Ireland than at any other time during the late-medieval centuries. These limitations may partly explain why correlations between the English and Irish oak chronologies become significantly weaker at this time (Fig. 4), although this may also reflect divergences in weather conditions at a time when atmospheric circulation patterns were in a state of flux. The scarcity of datable oak timbers is, of course, a consequence of the excess of felling over regeneration during the previous two centuries (Fig. 5B). But owing to the deteriorating security and economic situations, construction activity was also at a low ebb, with dwindling additions to the established stock of buildings.[158] Construction activity was also on the wane across the German- and French-speaking parts of the former Holy Roman Empire of the German Nation and in most parts of Europe investment in the building of new and enlargement of existing churches was being scaled down.[159] Everywhere, including Ireland, the high-medieval building boom was effectively over, partly because the great demographic and economic efflorescence that had long sustained it had run its course.[160] Nevertheless, society was not yet in full-scale retreat, witness the fact that as late as the 1320s in Ireland, marginally more oaks continued to be felled than were regenerating (Fig. 5B).[161]

Once the serious subsistence crisis of 1292–7 had passed, weather patterns across Ireland and Britain settled into a deceptively stable state, when all the available environmental indices—reconstructed Irish spring–summer soil moisture, European summer temperatures, Irish oak ring widths and English grain yields—display low year-on-year variability (Appendix 5). In fact, during the opening years of the fourteenth century the Index of Environmental

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[158] For the problems besetting the English Lordship from the 1280s: Duffy, *Ireland in the middle ages*, 128–33; Cormac Ó Cléirigh, 'The problems of defence: a regional case-study', in James Lydon (ed.), *Law and disorder in thirteenth-century Ireland: the Dublin parliament of 1297* (Dublin, 1997), 25–56; Campbell, 'Boom to bust'.

[159] Ljungqvist, 'Linking European building activity with plague history', 85–6; Buringh, 'Church building and the economy'.

[160] Campbell, *Great Transition*, 3–10, 267–77.

[161] Murphy, 'The economy', 410, finds 'some surprising evidence of economic resilience in the period between 1320 and 1340'. In contrast, Raymond Ruhaak, 'Towards an alternative Black Death narrative for Ireland: ecological and socio-economic divides on the medieval European frontier', *Journal of the North Atlantic* 39 (2019), 1–16: 9–12, infers significant woodland regeneration in north-east Ulster from the early fourteenth century based upon unspecified pollen evidence.

Instability subsided to a level not experienced since the late twelfth century (Fig. 1). This was just as well, for the outbreak of the Anglo-Scottish war in 1296, on top of the Anglo-French war of 1294, brought financial, political and military turbulence and uncertainty to the English Lordship of Ireland and the Lordship's internal borders came under increasing attack from the Gaelic Irish.[162] The only recorded instances of dearth were in the early summer of 1305, following a poor harvest in the previous year when in England, unusually, all grains had yielded poorly, and in 1310, following a 'hard spring' which hit English wheat yields hard, when the Anglo-Irish *Annals of Ireland, A.D. 1162–1370* also report a scarcity of grain and high prices.[163] Earlier, for 1308, the *Annals of Loch Cé* report '…there was destruction of people and cattle in it, and also great inclemency of weather in it' and thereby leave open whether these societal hardships were caused by the inclement weather or were merely coincidental.[164] Certainly in no case do the annalists explicitly describe conditions at this time as so bad as to amount to famine. For almost 20 years, then, following the extended crisis of 1292–7, no weather-related famine appears to have materialised. The draining of revenues, provisions and able-bodied men out of Ireland in support of the defence of Gascony and of Edward I's ambitious Scottish enterprise, disastrously continued by Edward II, ostensibly posed a far greater threat to the political, economic and demographic *status quo* than the weather.[165]

The comparatively moderate and settled weather of 1298 to 1314, which included a run of above-average summer temperatures in the Scottish Cairngorms, was, however, quite literally the lull before the storm.[166] Already, out in the North Atlantic, sea-surface temperatures were beginning to seesaw

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[162] James Lydon, 'The years of crisis, 1254–1315', in Cosgrove (ed.), *New history of Ireland, vol. 2*, 179–204: 196–204; Ó Cléirigh, 'The problems of defence'.

[163] For 1305, the *Annals of Inisfallen* uniquely report 'Great hardship at the beginning of the summer of this year': Ludlow, 'Utility 2', 241. 'Annals of Ireland', 339; Lyons, 'Weather, famine, pestilence and plague', 62. For 1310, the *Annals of Loch Cé* and *of Connacht* duplicate the reported 'hard spring', but without further detail regarding weather or impacts. The *Annals of Inisfallen* do report 'A very violent wind destroyed trees, houses and churches in the above year, and there was also a great crop of masts, nuts, and apples in the same year': Ludlow, 'Utility 2', 242–3. For yields in England: B.M.S. Campbell, *Three centuries of English crop yields, 1211–1491* (Belfast, 2007), www.cropyields.ac.uk. For a European perspective on this episode: Martin Bauch *et al*., 'A prequel to the Dantean Anomaly: the water seesaw and droughts of 1302–1307 in Europe', *Climate of the Past Discussions* (2020): 1–25.

[164] Ludlow, 'Utility 2', 241: The *Annals of Loch Cé* and *of Connacht* again duplicate this entry for 1308, with very similar phraseology and orthography in the underlying Irish: above note 40.

[165] Lydon, *Lordship of Ireland*, 131–4; Beth Hartland, 'The height of English power: 1250–1320', in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 222–43: 242–3; Campbell, 'Boom to bust'.

[166] Rydval, '800 years'.

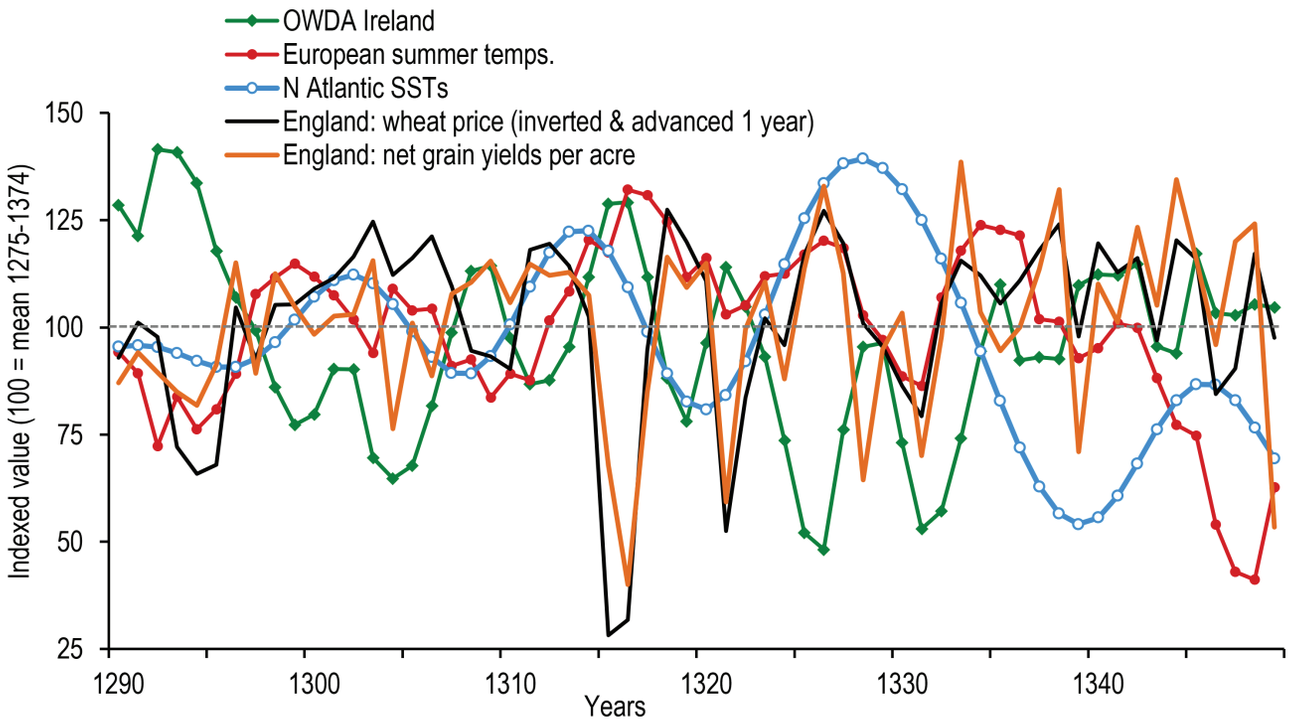

FIG. 7—Proxy measures of weather conditions affecting Ireland, 1290–1350 CE.

Note: all variables are indexed on their respective means for 1275–1374 and their variances standardised.

Sources: *North Atlantic sea-surface temperatures and European summer temperatures*: Appendix 1.

Irish OWDA (spring–summer soil moisture): Appendix 2.

English wheat prices (*inverted and advanced one year*) *and net grain yields per acre as deviations from trend*: sources to Fig. 5.

between warm and cold, with each swing more pronounced than the one before (Fig. 7). The warm episodes delivered a mild and humid airstream to Ireland and Britain, elevating precipitation, while the cold episodes had the opposite effect. The variance of annual North Atlantic sea-surface temperatures was rising from *c.*1300, became conspicuously inflated from 1313, and was exceptionally high from 1327–41, when the single greatest swing from warm to cold conditions occurred. Nevertheless, it was the warm episode of 1311–16 that had the more devastating consequences for food producers when '"overheating" of Atlantic surface ocean waters ... provided a source of moisture for prolonged summer rains as well as winter storms'.[167] Recent work on the marine equivalent of dendrochronology, namely examining temperature-sensitive annual shell-growth bands from the long-lived bivalve *Arctica islandica* in the North Sea, has also revealed marked variability

[167] A.G. Dawson *et al.*, 'Greenland (GISP2) ice core and historical indicators of complex North Atlantic climate changes during the fourteenth century', *The Holocene* 17:4 (2007), 427–34: 433; Campbell, 'Nature as historical protagonist', 293–4.

of sea surface temperatures in the 1290s, followed by a dramatic increase in mean temperatures through the first two decades of the 1300s, on a scale not seen in the remainder of this millennium-long reconstruction.[168] This short-term climate event (which has entered the historical lexicon as the 'Dantean Anomaly') came with heavy, persistent and untimely rain that ruined harvests across Ireland, Britain and much of Europe north of the Alps in 1315 and 1316 and triggered the Great Northern European Famine of those years.[169]

In England this is one of the greatest back-to-back yield failures on record and the consequent grain-price inflation was equally extreme (Fig. 7).[170] The ensuing full-scale agrarian crisis that ensued is well documented, as is the resulting excess mortality.[171] In Ireland, where the impact of the bad weather was massively compounded by a Scottish invasion, the crisis is likely to have been even more acute.[172] Although there are no Irish statistical series of yields and prices, palaeoclimatic reconstructions leave little doubt that Ireland experienced weather of comparable severity to England.[173] The *Annals of Loch Cé* testify that 1315 brought 'intolerable, destructive bad weather', while the *Annals of Clonmacnoise* elaborate slightly on what was a common earlier account from a shared exemplar, describing 'ugly and foul weather' in the summer.[174] Almost all annalists also

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[168] H.A. Holland *et al*., 'Decadal climate variability of the North Sea during the last millennium reconstructed from bivalve shells (*Arctica islandica*)', *The Holocene* 24:7 (2014), 771–86.

[169] The term was coined by Neville Brown, *History and climate change: a Eurocentric perspective* (London and New York, 2001), 251–4. It has since been employed by Campbell, 'Nature as historical protagonist', 287–301; Martin Bauch, 'The Dantean Anomaly (1309–1321): rapid climate change in late medieval Europe with a global perspective', *Mittelalter: Interdisziplinäre Forschung und Rezeptionsgeschichte* 1 (2018), 92–103; M. Bauch and G.J. Schenk (eds), *The crisis of the 14th century: teleconnections between environmental and societal change?* (Berlin, 2019).

[170] B.M.S. Campbell and Cormac Ó Gráda, 'Harvest shortfalls, grain prices, and famines in pre-industrial England', *Journal of Economic History* 71:4 (2011), 859–86: 869–71.

[171] Ian Kershaw, 'The Great Famine and agrarian crisis in England 1315–22', in R.H. Hilton (ed.), *Peasants, knights and heretics* (Cambridge, 1976), 85–132 (reprinted from *Past and Present* 59 (1973), 3–50); William Chester Jordan, *The Great Famine: Northern Europe in the early fourteenth century* (Princeton, 1996); Campbell, 'Nature as historical protagonist', 287–301; Jordan, *Great Famine*; Philip Slavin, *Experiencing famine in fourteenth-century Britain* (Turnhout, 2019).

[172] J. Lydon, 'The impact of the Bruce invasion', in Cosgrove (ed.), *New history of Ireland, vol. 2*, 275–302; Colm McNamee, *The wars of the Bruces: Scotland, England and Ireland, 1306–1328* (East Linton, 1997), 169–86; Brendan Smith, *Colonisation and conquest in medieval Ireland: the English in Louth, 1170–1330* (Cambridge, 1999), 105–12; Seán Duffy (ed.), *Robert the Bruce's Irish wars: the invasions of Ireland 1306–1329* (Stroud, 2002).

[173] Grace's *Annales Hiberniae* quotes a price of 24 shillings for a crannock of wheat in 1317 and 20 shillings in 1330: Ludlow, 'Utility 2', 252, 255. This compares with a price of at least 8 shillings a crannock in the crisis years of 1294–6 but only 2 shillings following the bumper harvest of 1286–7: Murphy and Potterton, *Dublin region in the middle ages*, 479.

[174] Ludlow, 'Utility 2', 244–51. The *Annals of Connacht* (also *Annals of Loch Cé* and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)) summarise 1315 thus: 'Many afflictions in

describe how the opposing armies of Edward Bruce and Richard Earl of Ulster were kept apart at Coleraine by the swollen waters of the swift-flowing River Bann.[175] The following year brought no let-up in the weather, when, as reported in the *Annals of St Mary's Abbey, Dublin*, 'tempests of wind and rain did great damage on land and sea'.[176] The resulting back-to-back harvest failure proved catastrophic so that by 1317, according to the *Annals of Connacht* (similarly reported in the *Annals of Ulster* and *of Clonmacnoise*), 'throughout Ireland' a 'great famine' prevailed, and 'many poor people perished of hunger and disease' (*Annals of Ireland, A.D. 1162–1370*).[177] These crisis conditions and the accompanying 'innumerable deaths' continued into 1318 when a winter of unusually heavy snow added to society's woes.[178] Not until late June did the prospect of a good harvest bring some easing of the situation, which was reinforced by the defeat and death of Edward Bruce at the Battle of Faughart on 14 October.[179]

None of Ireland's annalists leave any doubt that the depredations of Edward Bruce's for-long invincible Scottish army greatly magnified the misery inflicted by the weather during these three-and-a-half grim years.[180] The Scots, in requisitioning and destroying food stocks, caused many to abandon their homes and lands and flee as refugees, and so paralysed Church, state and civic society that they were rendered incapable of relieving the desperate situation and providing succour to the needy.[181] Campaigning amidst a famine-stricken landscape also contributed to the eventual failure of Edward Bruce's attempted conquest. Several annalists employed the classic famine trope of people resorting to cannibalism—last used in 1116 CE—to illustrate the breakdown of the moral order.[182] Such language conveys the impression that this famine was more

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all parts of Ireland: very many deaths, famine and many strange diseases, murders, and intolerable storms as well'.

[175] Ludlow, 'Utility 2', 244–51.

[176] Gilbert, *Chartularies of St. Mary's Abbey*, vol. 2, 298.

[177] Ludlow, 'Utility 2', 251–2; 'Annals of Ireland', 354.

[178] 'William Wilde's table of Irish famines', 5–6; Lyons, 'Weather, famine, pestilence and plague', 61–3. Ludlow, 'Utility 2', 252–3.

[179] G.O. Sayles, 'The Battle of Faughart', in G.A. Hayes-McCoy (ed.), *The Irish at war* (Cork, 1964), 23–34; 'Annals of Ireland', 359; Lyons, 'Weather, famine, pestilence and plague', 63.

[180] Owing to the adverse weather conditions, Hartland ('Height of English power', 226) considers it 'difficult to estimate the specific impact of the Bruce Invasion on the situation in Ireland'.

[181] Lydon, 'Impact of the Bruce invasion'; McNamee, *Wars of the Bruces*; Smith, *Colonisation and conquest*; Duffy, *Robert the Bruce's Irish wars*.

[182] For example, the *Annals of Clonmacnoise* (also *of Connacht*) reported (1318): '…for there reigned scarcity of victuals, breach of promises, ill performance of covenants, and loss of men and women throughout the whole realm for the space of three years and a half that he [Edward Bruce] bore sway. In so much that men did commonly eat one another for want of sustenance during this time': Ludlow, 'Utility 2', 251–2; Kelly, *Great dying,* 41; Cormac Ó Gráda, *Eating people is wrong, and other essays on famine, its past, and its future* (Princeton, 2015), 14–5, 25–6.

terrible than almost any that had gone before. Occurring after two centuries of population growth and reinforced by a deliberately destructive Scottish invasion, it was likely the greatest famine that late-medieval Ireland endured and in the suffering and excess mortality that it inflicted was maybe more terrible than the more graphically recorded contemporary catastrophe in England.

The damage inflicted upon capital stock by the Scots undoubtedly rendered post-famine recovery and reconstruction the more difficult and left the population more vulnerable to further weather extremes.[183] The return of wet and cold weather in 1321 therefore brought renewed hardship,[184] rendered all the more traumatic by the introduction to Ireland of the rinderpest panzootic—the *Mael Domnaig*—which had already devastated herds in England (Fig. 8). This was a virus that thrived when, as in 1321, temperatures were low and humidity high. The disease appears to have originated in Bohemia in 1316, when weather-induced ecological stresses were at their greatest, and thence spread ineluctably westwards at alarming speed to reach the Channel coast by 1318 and eastern England by Easter 1319.[185]

The Anglo-Irish *Annals of Ireland, A.D. 1162–1370*, and the Gaelic *Annals of Inisfallen, of Loch Cé*, *of Connacht, of Clonmacnoise* and *of Ulster* all make some cryptic note of the 'great cow-destruction throughout all Erinn, the like of which was not known before'.[186] Collectively, however, they are frustratingly silent on the contagiousness of its spread, the scale of the resultant mortality, the reduced milk yields and fertility of those animals that recovered, the effects upon arable production of the sudden death of many of the essential plough oxen, the time it took to make good the losses, and the repercussions of this epizoological disaster for the pastorally based economic and social order of much of the north and west of Ireland.[187] Certainly, the shock can hardly

[183] James Lydon, 'Ireland: politics, government and law', in S.H. Rigby (ed.), *A companion to Britain in the later middle ages* (Oxford, 2003), 335–56: 345–6.

[184] *Annals of Inisfallen* (1321): '…there was a great famine [*illegible*] in the same year': Ludlow, 'Utility 2', 253. These conditions appear replicated in Scotland: Oram, 'Worst disaster', 228.

[185] T.P. Newfield, 'A cattle panzootic in early fourteenth-century Europe', *Agricultural History Review* 57:2 (2009), 155–90; Campbell, *Great Transition*, 209–27.

[186] Ludlow, 'Utility 2', 253–4. The main text quote comes from the *Annals of Loch Cé*, an entry duplicated in the *Annals of Connacht*, *of Ulster* and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*). The report in the *Annals of Inisfallen* may be considered independent: 'A great murrain of the cows of Ireland in the above year, and there was a great famine [illegible] in the same year'.

[187] For the potential impact of cattle plague upon the Gaelic socio-political order of highland Scotland: R.D. Oram and W.P. Adderley, 'Lordship, land and environmental change in west Highland and Hebridean Scotland, *c*.1300 to *c*.1450', in Simonetta Cavaciocchi (ed.), *Le interazioni fra economia e ambiente biologico nell'Europe preindustriale, secc. XIII–XVIII* (Prato, 2010), 257–67: 262; R.D. Oram, 'Climate, weather and the rise of the Lordship of the Isles', in R.D. Oram (ed.), *The lordship of the isles* (Leiden, 2014), 40–61: 57–8.

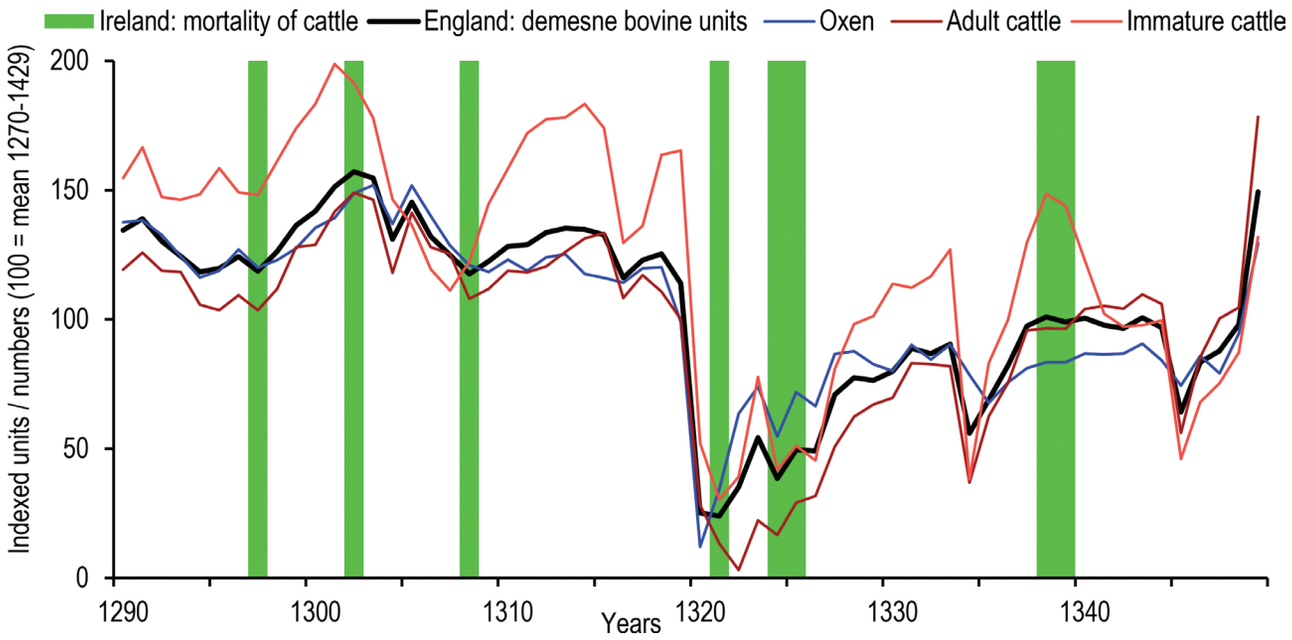

Fig. 8—Reports of mass cattle mortalities and murrains in the Gaelic and Anglo-Irish Annals and indexed numbers of cattle units on English demesnes, 1290–1350 CE.

Sources: *Reports of cattle mortalities and murrains in Ireland*: authors' own survey of Gaelic and Anglo-Irish Annals.

Cattle units on English demesnes (*oxen and cows* × *1.2* + *immature cattle* × *0.8*): B.M.S. Campbell, *The Great Transition: climate, disease and society in the late-medieval world* (Cambridge, 2016), 214, 223; Manorial Accounts Database.

have been smaller in pastoral Ireland than in mixed-farming England, where the overall bovine mortality rate has been estimated at 62 per cent and the national demesne herd sustained an immediate reduction of approximately 60 per cent (Fig. 8).[188] In Ireland, as in England, recovery was handicapped by repeat outbreaks of the disease, as explicitly reported by both the Gaelic Irish and Anglo-Irish Annals in 1324–5 and subsequently,[189] and these setbacks were

[188] Philip Slavin, 'The great bovine pestilence and its economic and environmental consequences in England and Wales, 1318–50', *Economic History Review* 65:4 (2012), 1239–66.

[189] Grace's *Annales Hiberniae* thus report for 1324, 'A murrain amongst oxen and the cows': *Jacobi Grace, Kilkenniensis*, 101. The (Gaelic) Annals confirm this report for 1324, with the *Annals of Loch Cé* noting 'The same cow-destruction in all Erinn in *hoc anno*; and it was it that was usually called the *Maeldomhnaigh*' (also in the *Annals of Ulster* and *of Connacht*). For 1325, the *Annals of Loch Cé* (also *of Connacht*, *of Ulster* and *of Clonmacnoise*) note 'The cow-destruction still throughout Erinn'. To compound these difficulties, the Annals see out the decade by reporting a visitation of epidemic disease in 1327, described in the *Annals of Loch Cé* (also *of Connacht*, *of Ulster*, and *of the Four Masters*) as 'A great epidemic of the *galar-brec* [literally, specked disease, taken as small pox by most editors of

compounded by harsh winter weather in 1338–9.[190] Since this was an enduring biological shock, as the example of England implies, full recovery to pre-1321 levels of stocking may have taken decades to achieve (Fig. 8). In effect, the cattle plague was the sting in the tail of a seven-year agrarian and military crisis that had begun in 1315 with the coincidental arrival of terrible weather and the Scots.[191] Nor did Ireland's sheep flocks, source of the wool that was the country's single most valuable export, escape unscathed, for in 1338 the *Annals of Loch Cé* and *of Connacht* report that 'the sheep of Erinn died in this year, excepting a few'.[192] No cause is given but sheep scab (which had devastated English flocks in 1279–80) and liverfluke (to which cattle are also susceptible) are prime suspects; the latter is caused by the flatworm *Fasciola Hepatica* which, along with the freshwater snails that are its intermediate host, thrives in rain-sodden pastures.

Meanwhile, as the twin dramas of the cattle plague and sheep murrain unfolded, weather conditions across Ireland remained decidedly unsettled. Following the Dantean Anomaly, the NAO weakened decisively (Appendix 3) with the result that in the mid 1320s and early 1330s Ireland experienced several consecutive years of unusually cold and dry weather, marked in the Irish oak chronology by the narrow ring years of 1325–6, 1334 and 1336 (Appendix 4).[193]

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the Annals] throughout all Erinn widely, which brought destruction on people small and great, in this year'. 1328 saw continued epidemic disease (now named the '*slaedan*' and apparently not small pox), extreme weather with thunder and lightning that damaged fruit and arable crops, a wind storm during summer and dearth of food and clothing, reported in the *Annals of Ulster*, *of Connacht*, *of Loch Cé*, *of Clonmacnoise* and *of the Four Masters*. See Ludlow, 'Utility 2', 109–11. Ludlow's compilation omits the cattle mortality reported in 1324, and smallpox in 1327 due to the lack of overt linkage to weather conditions. See https://celt.ucc.ie/publishd.html for the relevant texts in 1324 and 1327.

[190] 1338–9 (*Annals of Ulster*, also *of Connacht* and *of Clonmacnoise*): 'A great plague of snows and of frost prevailed that year from the beginning of a fortnight of winter [i.e., 15 November, if using the Celtic seasonal calendar] until a part of spring came, so that much of the cattle of Ireland suffered death and the green crops of Ireland went to nought the same year'. Likewise, for 1338, Grace's *Annales Hiberniae* reports 'Intense frost with very deep snow from the 2nd of December to the 10th of February': *Jacobi Grace, Kilkenniensis*, 131. See also 'Annals of Ireland', 362. The *Annals of Connacht* (also *of Clonmacnoise*) further report 'Great war all over Meath between Galls and Gaels. The corn crops of Ireland were destroyed and there was famine in the land'. See Ludlow, 'Utility 2', 257–8, for the Gaelic annalistic entries cited here.

[191] For the combined impacts of war, weather and disease in this period: B.M.S. Campbell, 'Ecology versus economics in late thirteenth- and early fourteenth-century English agriculture', in Del Sweeney (ed.), *Agriculture in the Middle Ages: technology, practice, and representation*, Philadelphia, 1995), 76–108; Campbell, 'Nature as historical protagonist'; Philip Slavin, 'Warfare and ecological destruction in early fourteenth-century British Isles', *Environmental History* 19 (2014), 528–50.

[192] 1338: see https://celt.ucc.ie/publishd.html for the relevant texts.

[193] Baillie, *New light*, 41–50, 107–11. For the situation in England: David Stone, 'The impact of drought in early fourteenth-century England', *Economic History Review* 67:2 (2014), 435–62; Pribyl and Cornes, 'Droughts in medieval and early modern England', 168–9.

Of these unusual conditions, however, the Gaelic Annals make no mention and, in fact, after 1338–9's report of cold conditions there is a significant decline in references to the weather for most of the remainder of the century (Fig. 2). What makes this development both surprising and frustrating is that the weather was taking an unusual turn, and the nominal level of recording of other events remained quite high (Figs 1 and 2).[194] The Anglo-Irish chronicles are marginally more informative and report the heavy and continuous rain, flooding and violent winds in 1330–31 that were responsible for the late and poor harvest of 1331 and the high Dublin grain prices that followed.[195] This was a bad harvest year in England, too, where low yields were followed by high prices (Fig. 7). This, however, was a crisis of one year's duration as, in its aftermath, the wet weather was replaced by dry. This culminated in the 'dry and fruitful summer' and early and abundant harvest of 1333 reported by the Anglo-Irish *Annals of Ireland, A.D. 1162–1370*,[196] while across the Irish Sea southern English demesnes enjoyed similar bumper yields (Fig. 6). It was a harvest that would not be bettered for over a hundred years.[197]

These comparatively benign weather conditions did not last for long. From the mid-1330s, sea-surface temperatures in the North Atlantic were cooling fast (Fig. 7). In 1335, great damage to wildlife was wrought by heavy snow in spring and then, in 1338–9, the long hard winter proved seriously harmful to livestock and crops alike (Fig. 8).[198] In both Dublin and Kilkenny winter began wet then in December turned so cold that the River Liffey froze for weeks.[199] The prolonged frost was followed by heavy snow, halting grass growth and blanketing the pastures upon which oxen, cows and sheep, more typically in Gaelic-dominated areas kept out of doors during the winter, depended for their

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[194] Baillie, *New light*, 30–9, 107–13; Ludlow, 'Assessing non-climatic influences'.

[195] *Annals of Ireland by Friar John Clyn,* 200–1; 'Annals of Ireland', 372, 373; 'William Wilde's table of Irish famines', 6; Lyons, 'Weather, famine, pestilence and plague', 65. Grace's *Annales Hiberniae* describes conditions for 1330: 'Most violent storms, by which a house was blown down which killed the wife of Milo Verdon and his daughter. There was also a great flood, especially of the Boyne, by which all the bridges on that river, except Babe's, were carried away, and other mischief done at Trim and Drogheda. A crannock of wheat is sold for 20s., [and] of oats for 8s., this scarcity was occasioned by the rainy season, on which account the greatest part of the wheat could not be reaped before Michaelmas': *Jacobi Grace, Kilkenniensis*, 117–9.

[196] 'Annals of Ireland', 380.

[197] Campbell, *Three centuries.*

[198] 1335 (*Annals of Clonmacnoise* (a.k.a. *Mageoghagan's Book*), also *of Connacht*): 'There was such great snow in the spring of this year that the most part of the small fowl of Ireland died'. 1338–9 (*Annals of Connacht*, also *of Ulster*): 'The cattle and winter grass of Ireland suffered much from frost and snow, which lasted from the end of the first fortnight in winter into spring' [note: the translation of '*gortaib gemair*' as 'winter grass' by A.M. Freeman (*Annals of Connacht*) is rendered 'green crops' by B. MacCarthy and W.M. Hennessy (*Annals of Ulster*)]: Ludlow, 'Utility 2', 257–8.

[199] *Annals of Ireland by Friar John Clyn*, 224–5; 'Annals of Ireland', 381.

frugal sustenance.[200] In the more mixed-farming countryside around Kilkenny, as Friar John Clyn reported, as well as heavy livestock losses, the autumn-sown grain crops were adversely affected.[201] The upshot, according to the *Annals of Connacht*, was that 'the corn crops of Ireland were destroyed and there was famine in the land'.[202] Similar difficulties beset English grain producers and problems returned on both sides of the Irish Sea in 1346, which was evidently as 'barren and costly' (*Annals of Friar John Clyn*) in Ireland as in England (Fig. 7).[203] The following year prices in England were high (Figs 6 and 8) and attempts to export grain provoked the first recorded English grain riots.[204] Edward III had already launched his ambitious and expensive invasion of France in the opening phase of the Hundred Years War, so the fiscal and economic situation was once again volatile and the capacity of both English and Irish society to cope with bad harvests correspondingly reduced.[205]

The timing of this new military initiative, and the strain it placed upon the financial resources of the English crown, could hardly have been worse since from the early 1340s another short-term global climate anomaly had begun.[206] Across Europe its onset was characterised by significant cooling of temperatures (Appendix 1), further weakening of the NAO (Appendix 3) and some violent oscillations in precipitation (Appendix 2). These sudden changes elevated the Index of Environmental Instability to a level not experienced since the late-eleventh century (Figs 1 and 7). Across the world from 1342 the cooler temperatures depressed tree growth.[207] The downturn, possibly initiated by the cumulative cooling effects of the Wolf Solar Minimum, was reinforced from 1341 by a notable

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[200] Ludlow, 'Utility 2', 257–8.

[201] *Annals of Ireland by Friar John Clyn,* 224–5.

[202] Ludlow, 'Utility 2', 257–8.

[203] *Annals of Ireland by Friar John Clyn*, 238–9. In England, autumn 1345 through to April 1346 were exceptionally wet, to the great harm of the autumn-sown crops: Britton, 'Meteorological chronology', 141.

[204] Buchanan Sharp, *Famine and scarcity in Late Medieval and Early Modern England* (Cambridge, 2016), 56–87; Buchanan Sharp, 'The food riots of 1347 and the medieval moral economy', in A. Randall and A. Charlesworth (eds), *Moral economy and popular protest: crowds, conflict and authority* (London, 2000), 35–54.

[205] H.G. Richardson and G.O. Sayles, 'Irish revenue, 1278–1384', *Proceedings of the Royal Irish Academy* 52C (1962), 87–100; W.M. Ormrod, 'The crown and the English economy, 1290–1348', in B.M.S. Campbell (ed.), *Before the Black Death: studies in the 'crisis' of the early fourteenth century* (Manchester, 1991), 149–83; W.M. Ormrod, 'The relative income from direct and indirect taxation in England, 1295–1454', in *European State Finances Database*: (2010), www.esfdb.org/table.aspx?resourceid=11762; Campbell, *Great Transition*, 267–71, 277–86.

[206] Campbell, *Great Transition*, 267–86.

[207] B.M.S. Campbell, 'Grain yields on English demesnes after the Black Death', in Mark Bailey and S.H. Rigby (eds), *Town and countryside in the age of the Black Death: essays in honour of John Hatcher* (Turnhout, 2012), 121–74: 122–47; Campbell, *Great Transition*, 277–9.

extratropical explosive eruption in the northern hemisphere, and then, particularly from 1344, by a much more substantial injection of sulphate into the high atmosphere by an unknown tropical eruption.[208] Cooling was at its most pronounced by 1348–9 (Fig. 1, Appendix 1).

Whether these climate forcings played any role in the first appearance of the bubonic plague in late-medieval Europe is not known, but this merits further scrutiny.[209] Regardless, from an origin in central Asia, the disease that has become known as the Black Death surfaced in the Crimea in 1345–46, whence it spread across the Black Sea and into the busy coastal ports of the Mediterranean in 1347. By 1348 it had crossed Europe to reach the south-coast English ports and east-coast Irish ports.[210] Its outbreak in England coincided with renewed bad weather and in 1349–51 a rare double back-to-back harvest failure, no doubt made much worse by dramatic plague-induced depletion of the agricultural labour force.[211]

Whether Irish harvests similarly plummeted in 1349–51 is unknown, for none of the Annals gives any hint of weather conditions, other than the (suggestive) report by Friar John Clyn that in 1349 there was a great scarcity of both corn and spices.[212] Irish (mostly Ulster) and English oak ring widths moved more-or-less in tandem during the 1340s but then deviated from 1354 (Appendix 4).[213] Narrow Irish oak rings in 1344 were followed by wide rings until 1349, consistent with the prevalence of cool wet weather during the growing seasons. Growth was then reduced from 1350 to 1352, with the latter being another narrow-ring year. In north-west Scotland, band widths from the Cnoc nam Uamh Cave speleothem suggest that 1341 and 1342 were exceptionally dry, 1348 and 1349 unusually wet and 1352 and 1353 moderately dry again, as the NAO swung between negative and positive modes (Appendix 3). In the northern Cairngorms, summer temperatures sank into a conspicuous trough from

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[208] Toohey and Sigl, 'Volcanic stratospheric sulfur injections', estimate the VSSI of the 1341 extratropical northern hemispheric event at 1.17 Tg, and the 1344 tropical event at 15.11 Tg; Sigl, 'Timing and climate forcing of volcanic eruptions' date the tropical event to 1345.

[209] Jürg Luterbacher *et al*., 'Past pandemics and climate variability across the Mediterranean', *Euro-Mediterranean Journal for Environmental Integration* 5:46 (2020), https://doi.org/10.1007/s41207-020-00197-5.

[210] Campbell, *Great Transition*, 300–5. For a detailed reconstruction of the spread of the Black Death across Europe: Ole J. Benedictow, *The Black Death 1346–1353: a complete history* (Woodbridge, 2004). The fullest contemporary account of the Black Death's arrival and spread in Ireland is given in *Annals of Friar John Clyn,* 246–53. Prevailing weather conditions in Ireland are discussed in Maria Kelly, *A history of the Black Death in Ireland* (Stroud, 2001), 32–3.

[211] Campbell and Ó Gráda, 'Harvest shortfalls, grain prices, and famines', 865–72; Campbell, 'Grain yields on English demesnes', 144–7.

[212] *Annals of Ireland by Friar John Clyn,* 252–3.

[213] Baillie, *New light*, 109.

1346–51, with 1348 the second coldest summer of the fourteenth century.[214] There is also the circumstantial evidence that, almost without exception from 1270 until 1346, poor harvest years in England were problem years in Ireland too. There is no reason to suppose that this correlation did not also hold to some extent in 1349–51 when the palaeoclimatic evidence implies that Irish grain producers faced the combined challenge of low temperatures and high rainfall. What is beyond doubt, however, is that Ireland did not escape the plague, whose fearful appearance aroused panic in the populace and prompted morbid comment in the Annals.[215]

As in the case of the earlier rinderpest panzootic, the reactivation of plague occurred in inner Eurasia under climatically-induced conditions of ecological stress.[216] Originally a zoonotic disease of wild ground-burrowing rodents, by degrees it was transformed into a fast-spreading pandemic whose invasion of north-western Europe coincided with the advent of unusual weather conditions arising from a pronounced global climate anomaly. Everywhere the impact of such a deadly disease upon biologically virgin human populations proved devastating and both in Ireland and England the resultant mortality greatly amplified the concurrent effects of the bad weather. Disease achieved what the weather alone did not and helped launch Irish society on a new trajectory. Ireland, in effect, was ensnared in global processes of climate reorganisation with which ecologically driven changes in the epidemiological environment were acting in concert, and all at a time when the country's economic, political and military situation was fast disimproving.[217] It was this conjuncture of circumstances that differentiated this climatic tipping point from all others and rendered its consequences so irreversible.[218]

1350–1450—contraction

By the early fourteenth century, European woodlands had been massively depleted by the cumulative impact of over two centuries of arable expansion, iron smelting and timber construction.[219] Jed Kaplan, Kristen Krumhardt and

[214] Rydval, '800 years'.

[215] Benedictow, *Black Death*, 143–5; Kelly, *History of the Black Death in Ireland*, 23, 34–8; Grace's *Annales Hiberniae* thus notes for 1348: 'Very great pestilence in Ireland, which had before gone through other countries': *Jacobi Grace, Kilkenniensis*, 143. Of Gaelic Annals, the *Annals of Ulster* (also *of Loch Cé*, *of Connacht*, *of the Four Masters* and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)) note for 1349 that: 'The great plague of the general disease that was throughout Ireland [prevailed] in Moylurg [Co. Roscommon] this year, so that great destruction of people was inflicted therein. Matthew, son of Cathal Ua Ruairc, died thereof': Ludlow, 'Utility 2', 259 (Ludlow reports only the entry from the *Annals of Ulster*; see https://celt.ucc.ie/publishd.html for the relevant additional texts).

[216] Campbell, *Great Transition*, 241–52.

[217] Campbell, *Great Transition*, 328–9; Duffy, *Ireland in the middle ages*, 148–51.

[218] Campbell, *Great Transition*, 10–15, 20–4, 332–5, 395–401.

[219] J.O. Kaplan, K.M. Krumhardt, and Niklaus Zimmermann, 'The prehistoric and preindustrial deforestation of Europe', *Quaternary Science Reviews* 28:27 (2009), 3016–34;

Niklaus Zimmermann reckon that between 1000 CE and the Black Death the share of usable agricultural land occupied by forest in central, alpine, northern and western Europe had reduced on average by 54–63 per cent.[220] They estimate the equivalent reduction in Ireland at 66 per cent. Certainly, the Irish oak chronology (Fig. 5) suggests that by 1340 CE the country's oak woodlands had been substantially reduced and building in oak had virtually ceased. Nevertheless, the 1320s was the last decade in which the number of oak-sample end dates exceeded the number of start dates. Thereafter, for the first time in almost 300 years, the balance tipped in favour of regeneration, almost imperceptibly at first but then with gathering momentum. There was a noticeable upturn in the pace of regeneration from the 1380s and with it, after a century almost devoid of samples (Fig. 5A), an increase in the number of oak samples from sites in Leinster and Munster. By the end of the fourteenth century, oak woodland was clearly becoming re-established in many parts of Ireland and it was at this time that numbers of the oaks felled in later centuries commenced their growth.[221] The change in the appearance of the Irish landscape, evident also to some extent in the country's pollen record, must have been considerable and exemplified a trend evident across Europe at this time.[222]

The catalyst for this sustained switch from depletion to regeneration was the substantial and abrupt reduction in population caused by the Black Death.[223] Mortality in the first wave of plague that struck England in 1348–9 is thought to have been at least 30 per cent and conclusive evidence remains to be presented that in Ireland, infected at the same time, mortality was substantially any less.[224] In its aftermath there was an immediate slump in construction activity almost

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Campbell, *Great Transition*, 148–9, 312–13. Stripped of their protective tree cover, Tuscany and parts of central Germany were plagued by floods and serious soil erosion: R.C. Hoffmann, *An environmental history of medieval Europe* (Cambridge, 2014), 325–7; Markus Dotterweich, 'The history of soil erosion and fluvial deposits in small catchments of central Europe: deciphering the long-term interaction between humans and the environment — a review', *Geomorphology* 101 (2008), 192–208. For the sparseness of woodland in much of lowland England by the early fourteenth century: B.M.S. Campbell and Ken Bartley, *England on the eve of the Black Death: an atlas of lay lordship, land, and wealth, 1300–49* (Manchester, 2006), 150–7.

[220] Kaplan, Krumhardt and Zimmermann, 'Prehistoric and preindustrial deforestation', 3023.

[221] In striking contrast, woodland remained scarce in Scotland and from 1450 eastern Scotland became increasingly dependent upon imported timber from Scandinavia and the Baltic: Crone and Watson, 'Sufficiency to scarcity', 80–1; Mills and Crone, 'Dendrochronological evidence', 29–31.

[222] Hall, *Making of Ireland's landscape*, 126–7; Büntgen, 'Filling the Eastern European gap', 1776; Lagerås, *Ecology of expansion and abandonment*, 77–92; Yeloff and Van Geel, 'Abandonment of farmland'.

[223] This was anticipated in the 1310s by the minor switch to regeneration that accompanied the Dantean Anomaly and followed the Bruce Invasion (Fig. 5).

[224] Campbell, *Great Transition*, 306–13; Murphy, 'The economy', 409–10.

everywhere and building workers found that there was a corresponding fall in demand for their labour.[225] With perhaps a third fewer mouths to be fed and a corresponding contraction in the available agricultural labour force, much land was withdrawn from cultivation. Arable land was converted to grass, thereby reinforcing the strong pastoral bias of Irish agriculture, and a great deal of land, especially the more marginal, was allowed to revert to woodland.[226] In Ireland, oaks were among the dendrological beneficiaries of the latter significant and, as it turned out, enduring land-use shift. Their re-advance (Fig. 5) is a clear indication that the era of declining land to labour ratios and mounting resource scarcity was over. A new age had dawned, characterised by reduced and reducing population densities, a profound and lasting transformation of the epidemiological environment, and a progressive weakening of English crown authority.[227] A new socio-ecological equilibrium was in the process of becoming established and the prospects of any return to the *status quo ante* were increasingly remote.

What now preoccupied Ireland's new breed of non-monastic and secular annalists, as is clearly apparent in Fig. 9, was not the triumvirate of bad weather, famine and war, although violence and fighting remained relatively commonplace, but plague and the sudden death of great men because of it (Fig. 2). The fates of women, other than the obits of high-ranking females, and of ordinary people, unless dying *en masse* and within the annalist's geographical sphere of interest, were mostly not deemed of relevance. Thus, only in 1349, a year following the plague's first arrival on the island when it reached into a Gaelic heartland, west of the Shannon, and only when an important member of the Gaelic nobility—Matthew, son of Cathal O'Rourke—had succumbed, do the surviving Gaelic Annals note plague's existence.[228] Explicitly quantitative reports of the scale of plague mortality are also few and far between and mostly concern Dublin.[229] The Anglo-Irish Latin chroniclers of the English Lordship are barely more informative; witness the generalised description respecting the third plague of 1370 in the *Annals of Ireland, A.D. 1162–1370* that 'countless nobles, townsmen and children died'.[230]

Usefully, the Anglo-Irish *Annals of Ross* identify five distinct Irish plague pandemics over the course of the fourteenth century: the first in 1348–9, the second in 1361–2, the third in 1370–1, the fourth in 1382–5 and the fifth in 1391 (Fig. 8).[231] The Gaelic Annals do attest to large outbreaks in most of

[225] Campbell, *Great Transition*, 310–12.
[226] Nicholls, 'Woodland cover', 186–9, 202–3.
[227] James Lydon, *Ireland in the later middle ages* (Dublin, 1973), 77–152.
[228] Ludlow, 'Utility 2', 259.
[229] The *Annals of the Four Masters* reported the deaths from plague of 3,000 Dubliners in 1439: https://celt.ucc.ie//published/T100005D/index.html (M1439.16); Kelly, *Great dying.*
[230] 'Annals of Ireland', 397.
[231] 'The Annals of Ross', in Richard Butler (ed.), *The Annals of Ireland by Friar John Clyn, of the convent of Friars Minor, Kilkenny; and Thady Dowling, Chancellor of Leighlin; together with the Annals of Ross* (Dublin, 1849), 38.

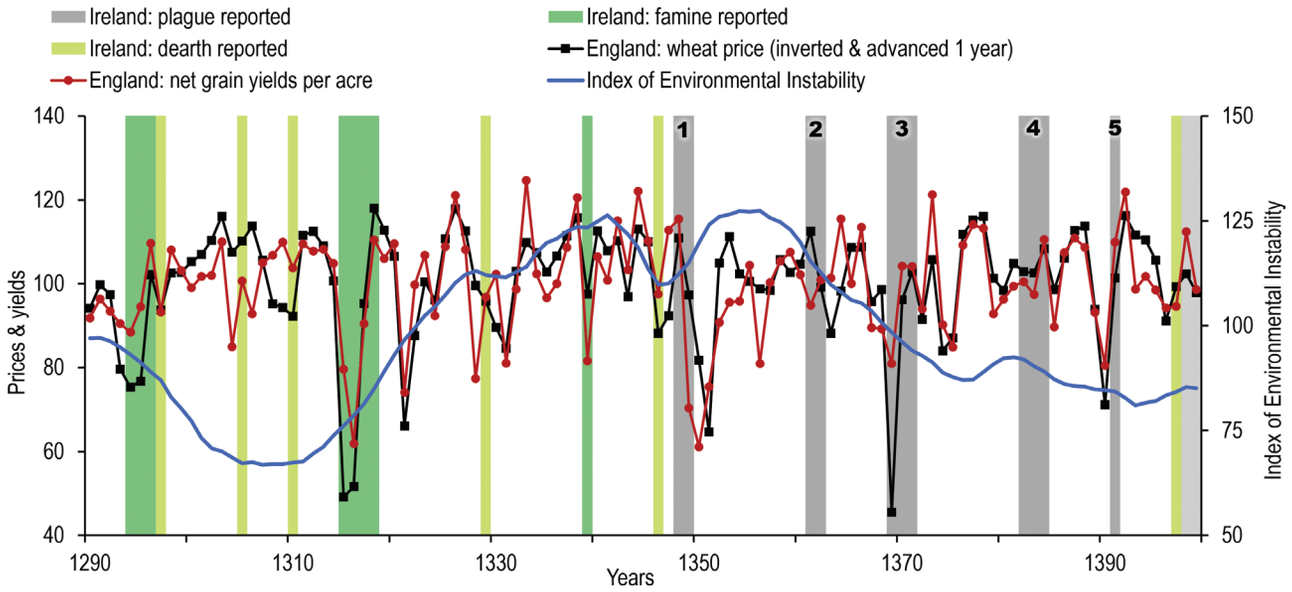

FIG. 9—Reports in the Gaelic and Anglo-Irish Annals of dearth, famine and plague in Ireland, alongside English wheat prices and net grain yields and an Index of Environmental Instability, 1290–1400 CE.

Sources: *Dearth, famine and plague in Ireland*: authors' own survey of Gaelic and Anglo-Irish Annals.

Wheat prices (percentage of 25-year moving average centred, inverted and advanced one year); net grain yields per acre (deviations from trend in net wheat-barley-oats [W-B-O] yields, averaged using the weighted ratio 2:1:1); Index of Environmental Instability: see sources to Fig. 5.

these cases, but note individual instances of the death of notable persons from the third plague in 1369 rather than 1370 and add a sixth widespread event—'A great plague this year' (*Annals of Connacht*)—in 1398.[232] These synchronise well

[232] For the fourteenth century, the Gaelic Annals report widespread plague in 1349 (*Annals of Loch Cé*, *of Connacht*, *of Ulster*, *of the Four Masters*, and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)), 1361 (*Annals of Loch Cé*, *of Connacht*, *of Ulster*, *of the Four Masters*, with further reports of notable individuals dying of the disease in 1362, but no explicit statement of a continuance of a widespread outbreak), 1383 (*Annals of the Four Masters*, *Annals of Clonmacnoise* (a.k.a. *Mageoghagan's Book*), and with reports of notables dying from plague in 1384 but again without explicit attestation of more general severity or geographical scope), 1392–3 (*Miscellaneous Irish Annals – Fragment 3 – Annals of Oileán na Naomh*; but without explicit use of the word 'plague') and 1398 (*Annals of Loch Cé*, *of Connacht*, *of the Four Masters* and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)), with notables again dying in 1399 and 1400 from plague, but no confirmation of broader severity or scope). No explicit Gaelic attestation of a widespread outbreak is given for 1370–1 (as per the *Annals of Ross*), but the *Annals of Ulster* attest to several notables dying of plague in 1369. Lastly, the *Annals of Ulster* for 1376 note the death of just one individual from plague—this is the only instance during these years in which an explicit plague attestation is unrelated (falling either in the same or an adjacent year) to a wider outbreak noted either within the Gaelic Annals or Anglo-Irish Annals. See https://celt.ucc.ie//published for the relevant texts.

with more comprehensively documented English plague outbreaks in 1348–9, 1361–2, 1368–9, 1382 and 1391, of which the first two were the most devastating and the cumulative effect of all five was to reduce that country's population by at least half.[233] In Ireland the combined demographic impact of these same five plague outbreaks may credibly have been similar, but this awaits confirmation.

Especially intriguing, given the ecologically sensitive character of this host- and vector-dependent disease, is the close association between the poor harvests of 1349, 1361, 1369 and 1390 and plague outbreaks in the same or sequel years.[234] In fact, an initial statistical analysis of English harvest yields and Jean-Noël Biraben's counts of reported plague outbreaks in Europe (between 1346 and 1476) reveals a statistically significant negative correlation, with plague counts rising in bad harvest years and falling in abundant harvest years.[235] Harvests are, of course, also influenced by human factors, not least the incidence of plague itself, which may reduce the availability of labour to sow and especially harvest crops and disrupt the continuity of management. This may explain why harvests following within one or two years of a plague outbreak also tended to be reduced.[236] This observation highlights the complexity of the interactions between the human and natural systems under examination, in which depressed harvests might be caused by bad weather and plague outbreaks acting both independently or together. In this materially poor society, harvest shortfalls, in turn, will have adversely affected nutrition and thereby morbidity and mortality and, through scarcity-induced migration, may have further encouraged the

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[233] S.K. Cohn Jr, *The Black Death transformed: disease and culture in early renaissance Europe* (London, 2002), 184–5, 197; Broadberry, *British economic growth*, 12–15; Campbell, *Great Transition*, 311, 313–19.

[234] Campbell, *Three centuries*; 'Annals of Ross', 38.

[235] The Pearson correlation value for English grain yields versus plague incidence between 1346 and 1476 amounts to r = -0.214, a moderate negative correlation, but statistically highly significant with p = 0.014 (i.e., there is only a 1.4 per cent chance that the observed correlation could have arisen purely by chance). The sources upon which this analysis are based are Campbell, *Three centuries,* and Jean-Noël Biraben, *Les hommes et la peste en France et dans les pays européens et méditerranéens*, *vol. 1: la peste dans l'histoire* (Paris and The Hague, 1975), 363–74; U. Büntgen *et al*., 'Digitizing historical plague', *Clinical Infectious Diseases* 55:11 (2012), 1586–8. There are well-known drawbacks to the Biraben dataset: Joris Roosen and D.R. Curtis, 'Dangers of noncritical use of historical plague data', *Emerging Infectious Diseases* 24:1 (2018), 103–10 (but these are rebutted by Ole Jørgen Benedictow, 'Biraben's lists of the plague epidemics of the second plague pandemic, 1346–*c*.1690: problems, basis, uses', *Annales de Démographie Historique* 138:2 (2019), 213–23).

[236] Pearson cross-correlation values show that for any given year's harvest, plague incidence in the second year preceding correlated negatively at r = -0.233 and p = 0.008 (i.e., there is a 0.8 per cent chance that the observed correlation has arisen by chance). Plague incidence for the first year preceding is also negatively correlated at r = -0.326 and p = 0.0002 (i.e., there is just a 0.02 per cent chance that the observed correlation has arisen by chance).

spread of disease or relocated rural populations to urban locations with higher infection rates.

Weather conditions, especially temperature and humidity levels, also powerfully influenced the ecological interlinkages between the plague bacterium (*Yersinia pestis*), its wild and domestic mammalian hosts, the insect vectors—mostly fleas but also, possibly, lice—by which it was spread, and its human victims.[237] This is evident in the statistically significant negative correlation to be observed between recorded plague outbreaks and reconstructed European summer temperatures across the years 1346 to 1499, with cooler summers associated with increased counts of plague outbreaks in the same year and vice versa.[238] Cross-correlation reveals a lagged and/or multi-year response, in which lower summer temperatures in each of the three years preceding a given year also tend to be associated with a higher incidence of reported plague outbreaks in that given year.[239] For medieval Ireland, the available data are not particularly suited to correlation analysis, but an assessment of the association between plague incidence in Ireland and weather conditions can be undertaken by conducting a further set of superposed epoch analyses in which the timing and frequency of epidemics reported in the Annals is examined relative to the date of major explosive volcanic eruptions (Appendix 7). This reveals a statistically significant increase (at $p = 0.06$ for the post-1348 era) in the reporting of epidemics in the year of volcanic eruptions, attesting to an association between volcanically induced climatic stress and disease outbreaks in Ireland. These implied climate–plague interactions may have operated through the reactivation of local European reservoirs of infection or by intensifying the severity of plague outbreaks already

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[237] Campbell, *Great Transition*, 228–9, 286–9, 295–9.

[238] The strength of this association is moderate, at $r = -0.297$ (Pearson correlation coefficient), leaving room for many other influences (including other weather variables such as precipitation) on plague frequencies beyond summer temperatures. It is, however, statistically highly significant, with just a 0.02 per cent probability of having occurred purely by chance (i.e., $p = 0.0002$). The sources upon which this analysis are based are Biraben, *Les hommes et la peste*, *vol. 1*, 363–74; Büntgen *et al*., 'Digitizing historical plague'; PAGES2k Consortium, 'Continental-scale temperature variability during the past two millennia,' *Nature Geoscience* 6 (2013), 339–46.

[239] For the third, second and first years preceding, statistically significant negative Pearson correlation coefficients (at the 5 per cent or $p = 0.05$ level) are observed between summer temperatures and plague incidence of, respectively, $r = -0.161$ ($p = 0.048$), $r = -0.247$ ($p = 0.002$), and $r = -0.217$ ($p = 0.007$). European summer temperatures are themselves correlated positively with English harvest yields, but only statistically significantly for the second and third years preceding, respectively $r = 0.158$ ($p = 0.073$), and $r = 0.208$ ($p = 0.017$). These correlations, although not strong, suggest that temperatures may have acted upon plague incidence via their effects on harvest yields. Paradoxically, temperatures do not exhibit any clear correlation with harvests in the same years (i.e., this year's summer temperatures are not strongly correlated with this year's harvests), but do influence plague incidence in the same years, implying other temperature-related influences on plague incidence are also at play.

occurring. On a larger geographical scale and longer time-frames, climatic factors are likely to have triggered (with a 10–12-year lag) the periodic reintroduction of plague to Europe from its heartlands in Asia's continental interior.[240] These mechanisms are certainly not mutually exclusive.

These observations suggest that in this new epidemiological environment the more critical association for society at large had become that between the weather and plague rather than the weather and food scarcity. Indeed, with more land to go around and fewer people to be fed, the risk of dearth escalating into full-scale famine was significantly diminished. Across Europe, in fact, during the land-abundant century-and-a-half that followed the Black Death, there is a conspicuous reduction in the number of recorded subsistence crises and famines.[241] Irrespective of climatic trends and weather conditions, acute scarcity was for the moment something that fewer people had to fear.

The unstable and inclement weather with which arrival of the Black Death coincided persisted for some years afterwards and was much commented upon by English chroniclers.[242] These years witnessed some of the most repeatedly below-average English harvests on record.[243] Yet in Ireland whatever the weather was doing attracted significantly diminished comment by the country's annalists (Fig. 2). Only the most unusual meteorological occurrences, or those damaging to physical infrastructure, were recorded. These include, in 1358, a hail storm with stones the size of crab apples at Carbury, Co. Sligo,[244] the devastating

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[240] K.L. Kausrud *et al*., 'Modeling the epidemiological history of plague in Central Asia: palaeoclimatic forcing on a disease system over the past millennium', *BMC Biology* 8:112 (2010), 14; Schmid, 'Climate-driven introduction of the Black Death'. The lagged introduction of plague to Europe is consistent with statistically significant negative correlations between European summer temperatures and Biraben's plague incidence with lags of 12–13 years (having examined the preceding 30 years in the present study) with $r = -0.365$ ($p < 0.001$) and $r = -0.332$ ($p < 0.001$), respectively.

[241] Guido Alfani and Cormac Ó Gráda, 'Famines in Europe: an overview', in Guido Alfani and Cormac Ó Gráda (eds), *Famine in European history* (Cambridge, 2017), 1–24: 8–9.

[242] There is, for example, no counterpart in the Irish sources to Henry Knighton's account of the wintry weather that persisted from 6 Dec. 1353 until 12 Mar. 1354: 'there was a long, hard and cold winter. It began at the feast of St Nicholas and lasted continuously until the feast of St Gregory: and there followed a great and severe storm of wind destroying the roofs of churches, mills and great trees, and doing much damage: such a tempest had not been seen in our day': Britton, 'Meteorological chronology', 142, also 141–6.

[243] Campbell, 'Grain yields on English demesnes', 147–9.

[244] Reported in the *Annals of Ulster* (also *of Connacht*, *of the Four Masters*, and *of Clonmacnoise* (a.k.a. *Mageoghagan's Book*)): 'A great [hail] shower came in that summer in Carbury [Co. Sligo] and not less than a very ripe [full-grown] apple was every stone of them': Ludlow, 'Utility 2', 260–1.

St Maur's Day wind on 15 January 1362,[245] and in the *Annals of Connacht* (also *of Ulster*) for 1373 another 'very great wind…which wrecked many churches'.[246] Of bad weather, poor harvests and scarcity there is no mention until 1397, when reference is made in the *Miscellaneous Irish Annals* to 'insufficiency of food in the summer, and the autumn wet, windy, destructive and cold'.[247] For once, in contrast to earlier weather-related crises, C.E. Britton reports no corresponding complaint made by English chroniclers about the weather that same year.[248]

Until this point, the indifference of both Gaelic and Anglo-Irish annalists to the weather is striking. Good and (presumably) bad harvests alike passed without mention. Thus, the better weather that prevailed during the Chaucerian Solar Maximum is ignored, notwithstanding that England enjoyed harvests so bountiful in the 1370s and 1380s that they initiated a prolonged grain-price deflation which on many estates brought the era of direct demesne management to an end.[249] It is as though, in an age overwhelmed by repeated tsunamis of plague (Fig. 9), the weather scarcely merited a mention when it came to chronicling important events. Possibly, too, with a reduced, more resilient and more pastoral population, harsh weather was less likely to translate into serious subsistence crises. What is plain is that in Ireland as well as England the return to more settled and clement weather during the final decades of the fourteenth century and opening decades of the fifteenth century (Fig. 1), in combination with re-establishment of favourable land to labour ratios and, in the case of England, materially improved living standards, were still insufficient to halt the demographic rot and set their depleted populations back on the road to recovery.[250] For almost another hundred years, and possibly considerably longer in Ireland, the countervailing effect of high disease mortality hindered positive rates of natural increase from becoming established. Security problems arising from the waning authority and shrinking territorial control of the English administration in Ireland and

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[245] Carefully calibrated English sources date this gale reliably to 15 January 1362. Grace's *Annales Hiberniae* reports this event under 1361 as 'A great storm on the feast of St. Maur': *Jacobi Grace, Kilkenniensis*, 153. The dating system employed by the *Annales Hiberniae* correctly puts the storm in 1362. The *Annals of Connacht* (also *of Ulster*, *of Loch Cé*, and *of the Four Masters*) also report a 'Great wind … which wrecked churches and houses and sank many ships and boats', but for 1363: Ludlow, 'Utility 2', 261. While the first two St Maur's Day events are undoubtedly the same it is conceivable that the last is distinct.

[246] Ludlow, 'Utility 2', 263. Was this the same gale that in Scotland damaged property and flattened woodland but is retrospectively dated by fifteenth-century Walter Bower to December 1372? (Oram, 'Worst disaster', 228).

[247] Ludlow, 'Utility 2', 264; Lyons, 'Weather, famine, pestilence and plague', 67.

[248] Britton, 'Meteorological chronology', 152.

[249] Campbell, 'Grain yields on English demesnes', 141, 149–51.

[250] Broadberry, *British economic growth*, 13–22, 203–8, 229–34; Jane Humphries and Jacob Weisdorf, 'Unreal wages? Real income and economic growth in England, 1260–1850', *Economic Journal* 129 (2019), 2867–87.

resurgent rivalries and conflicts between Anglo-Irish and Gaelic lords, may have been a further factor keeping replacement rates in check.

Owing to their preoccupation with the deaths of prominent individuals, Ireland's annalists never abandoned their interest in plague and they continued to note related fatalities even after the great initial pandemic outbreaks of the fourteenth century had ended (Fig. 9). Both larger outbreaks and the plague deaths of notable persons are frequently recorded throughout the fifteenth century and imply that the disease was repeatedly re-introduced to Ireland, as in 1478 when 'A great plague came in a ship to the harbour of Assaroe [Co. Donegal] and that plague spread throughout Tirconnell [Co. Donegal], and in Fermanagh and in the Province [of Ulster] in general'.[251] Dublin is, however, likely to have been its most common port of entry. In 1439, '… three thousand persons, both male and female, large and small, died of it [in Dublin], from the beginning of spring to the end of the month of May…' (*Annals of the Four Masters*).[252] Eight years later, in 1447, 'it is difficult to get an account of the innumerable multitudes that died in Dublin by that plague'.[253] On this occasion Meath, Munster and Leinster also became infected, as plague presumably circulated from Dublin to other towns and settlements within the English Lordship, with the *Annals of the Four Masters* adding that 'some say that seven hundred priests died of this plague'.[254] Nor, given the numbers of plague deaths recorded in the Gaelic Annals, in addition to reports such as the above-cited plague-bearing ship arriving in County Donegal in 1478, should it be supposed that the more thinly peopled and pastoral regions of the north and west were little visited by the disease.[255] The initial sparseness of plague citations in the Gaelic Annals from 1349 might suggest that to begin with these regions got off more lightly than the more closely settled mixed-farming regions

[251] Reported in the *Annals of Ulster* (also *of the Four Masters* and *of Loch Cé*—though the latter dates the event to 1477). See https://celt.ucc.ie//published/ for the relevant texts.

[252] https://celt.ucc.ie//published/T100005D/index.html (M1439.16).

[253] John O'Donovan (ed.), 'The Annals of Ireland, from the year 1443 to 1468, translated from the Irish by Dudley Firbisse…', *The Miscellany of the Irish Archaeological Society* 1 (1845), 198–301: 218.

[254] https://celt.ucc.ie//published/T100005D/index.html (M1447.2). Beyond the *Annals of the Four Masters* here, and 'Annals of Ireland, from the year 1443 to 1468' above, widespread plague conditions are also reported this year in the *Annals of Ulster* (https://celt.ucc.ie//published/T100001C/index.html (U1447.8)).

[255] For a recent reiteration of, and ecological justification for, the oft-cited view (which has similarly been advanced for Scotland) that the Gaelic regions of the north and west were less impacted by plague: Ruhaak, 'Alternative Black Death narrative', 1–16. This might be tested by mapping all plague deaths in the Gaelic and Anglo-Irish Annals against high-resolution regional pollen profiles. For Scotland, however, Oram ('Worst disaster', 231) has emphasised that 'there is no evidence to support views that plague was ever purely or even largely an urban problem in later medieval Scotland, or that rural populations were any less severely affected by plague epidemics'.

of the south and east, as remarked by some contemporaries.[256] Nevertheless, at least from the 1380s, as oak regeneration became established across the island (Fig. 5), references to plague deaths in the Annals increase (Fig. 2), with the implication that a process of epidemiological levelling-up was taking place. Certainly, the frequency with which the fifteenth-century Annals report notable individuals, both Gaelic and English, succumbing to sickness and disease implies that plague and the other diseases circulating at this time were widespread in their impacts.[257] Ultimately, therefore, morbidity and mortality rates in both communities may have become relatively high.[258]

References to weather also re-appear in the fifteenth-century Annals (Fig. 2) and are a reminder of its continuing capacity to cause hardship and havoc even in an era of relative land abundance. Between 1406 and 1409 a run of poor harvests in England (Fig.10) were closely matched by a sequence of weather-related problems in Ireland. These began in the winter of 1405 with 'very tempestuous weather and very heavy rainfall … causing much destruction' (*Miscellaneous Irish Annals*), continued in 1407 with 'foul and bad weather and a great murrain of cattle' (*Annals of Clonmacnoise*; also *of Connacht* and *Miscellaneous Irish Annals*), and then, possibly with a greater implicit focus on the lands of the English Lordship, culminated in 1410 with 'great famine in Ireland' (*Annals of Thady Dowling*).[259] At much the same time outbreaks of plague were reported on both islands: in England in 1405, 1406 and 1407 (triggering a spate of will-making in London) and then, with a characteristic lag of a year, in Ireland in 1406 and 1408.[260]

Directly and indirectly, the bad weather very likely facilitated the re-emergence, intensification and diffusion of plague in these years. This, in turn,

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[256] Maria Kelly, '"Unheard-of mortality": the Black Death in Ireland', *History Ireland* 9:4 (2001), 12–7.

[257] The Annals frequently eschew detailed descriptions and diagnoses of the cause of death. Typical are the unspecific accounts of '*dith mor*' ('great destruction', as per 1406) or the somewhat more specific '*pestilencia magna*' ('great pestilence', as per 1408). Often, explicit mention is made of 'plague', as in 1406 (*Annals of Connacht*, also *of Loch Cé*)) when various named notables '… *mortui sunt don plaig in hoc anno*' ('…died of the plague in this year'): https://celt.ucc.ie/published/G100011/text174.html (1406.2). Such a description is still somewhat ambiguous as to the underlying pathogen, but a broad view is taken in identifying possible bubonic plague incidence (Fig. 10). This is an area of annalistic reporting that merits further study.

[258] For the situation in fifteenth-century England, where disease mortality remained high and the downward demographic trend was not arrested until the middle years of the century: Campbell, *Great Transition*, 349–55.

[259] Ludlow, 'Utility 2', 265–6; Richard Butler (ed.) 'The Annals of Thady Dowling, Chancellor of Leighlin', in *Annals of Ireland by Friar John Clyn*, 27; 'William Wilde's table of Irish famines', 6; Lyons, 'Weather, famine, pestilence and plague', 68.

[260] Biraben, *Les hommes et la peste*, *vol. 1*, 363–74; Cohn, *Black Death transformed*, 197; *Annals of Loch Cé*, *of Connacht*, *of Clonmacnoise*, and *Miscellaneous Irish Annals – Fragment 3 – Annals of Oileán na Naomh*: Ludlow, 'Utility 2', 266; Lyons, 'Weather, famine, pestilence and plague', 68. The close chronological juxtaposition of these English and Irish plague outbreaks helps clinch their identification.

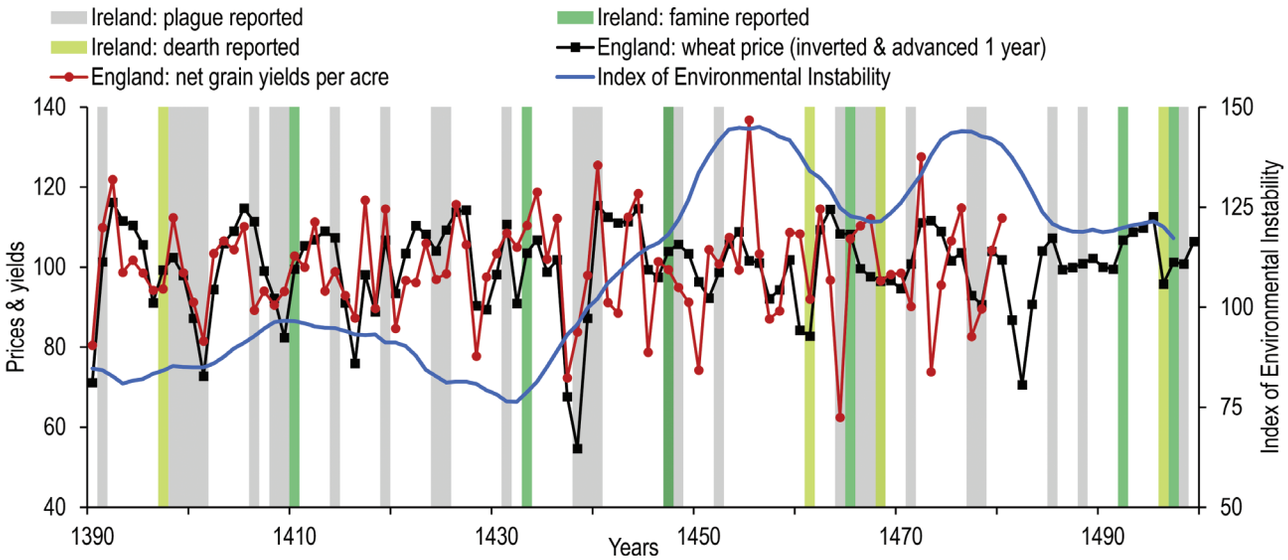

Fig. 10—Reports in the Gaelic and Anglo-Irish Annals of dearth, famine and plague in Ireland, alongside English wheat prices and net grain yields and an Index of Environmental Instability, 1390–1500 CE.

Sources: *Dearth, famine and plague in Ireland*: authors' own survey of Gaelic and Anglo-Irish Annals.

Wheat prices (percentage of 25-year moving average centred, inverted and advanced one year); net grain yields per acre (deviations from trend in net wheat-barley-oats [W-B-O] yields, averaged using the weighted ratio 2:1:1); Index of Environmental Instability: see sources to Fig. 5.

compounded the social impacts of poor harvests and cattle murrains and made these years deadly on both sides of the Irish Sea. Plague broke out again in Meath and Leinster in 1414, despite the intervention in 1411 of 'The Holy Cross at Raphoe [which] shed blood from the wounds this year and performed many miracles, checking sicknesses and many ills'.[261] Five years later in 1419 the *Annals of Connacht* reported 'much plague in England and in Ireland', although in Ireland this was apparently better remembered as 'the year of the hot summer', when 'burning heat' and drought extended from summer into autumn (*Annals of Connacht*).[262] As in England, this resulted not in scarcity but in 'a great yield of

[261] *Annals of Connacht* (also *of Loch Cé*, *of the Four Masters* and *of Ulster*): https://celt.ucc.ie/published/T100011/text179.html (1411.24). Such reports offer a window into how the annalists (representative of the educated Gaelic elite) contextualised the new disease environment of the fourteenth and fifteenth centuries.

[262] Also reported in the *Annals of Ulster*: Ludlow, 'Utility 2', 269–70; Lyons, 'Weather, famine, pestilence and plague', 68. This drought is confirmed by the OWDA, registering as severe throughout Britain and Ireland and across north, north-west, central and eastern Europe: Cook, 'Old World megadroughts'. The summer heat did not apparently extend to include the Scottish Cairngorms, where 1419 marks the start of a 20-year decline in summer temperatures: Rydvale, '800 years'.

every fruit and crop'.[263] Thereafter, northern hemisphere temperatures cooled, atmospheric circulation patterns decisively shifted, the NAO switched from predominantly positive to negative modes (it was negative for three out of five years during the fifteenth century and seven out of ten years between 1425 and 1474: Appendix 3), and environmental instability rose once again (Fig. 1 and Appendix 5). The upshot was that the synchronicity of weather patterns and impacts which had hitherto prevailed between Ireland and England appears to have weakened and on occasion lapsed altogether.

Correlations between the ring widths of Irish and English oaks, which had been so strongly positive when the circulation patterns of the Medieval Climate Anomaly had been firmly in the ascendant from the 1170s to 1260s, were significantly weaker during the opening phase of the Little Ice Age in the fifteenth century (Fig. 4). In fact, during the middle years of that century there were periods when growing conditions in Ireland diverged so widely from those in England that there was effectively no correlation at all, and for short periods, notably 1452–3 and 1462–6, correlations actually turned negative. This may explain why there was no equivalent in England to the 'great inclemency' of (presumably) November 1424 to May 1425 reported by the *Annals of Ulster*, which 'brought great destruction on cattle and loss of tillage and loss of people on the whole of Ireland'.[264] Although this Irish episode does coincide with worsening summer temperatures in the Scottish Cairngorms, a stark distinction between Irish and English weather conditions (in terms of wetness) is well captured by the Old World Drought Atlas.[265] Conversely, on the silence of the Annals, Ireland seems to have escaped the worst of the wet weather that in 1428 ruined the English wheat harvest (Fig.10).[266] Spring-sown oats, in contrast, yielded at well above average, which may explain why there is no mention of subsistence difficulties in the oats-growing north and west of Ireland.[267] Certainly, the Old World Drought Atlas indicates that in 1428 wet weather conditions prevailed right across Britain and Ireland, including the western and northern domains of most Gaelic annalists. Consequently, this may be a case of divergent impacts, in which the oats- and grass-growing Gaelic and 'Gaelicising' areas were less sensitive to the wet conditions that were so damaging to the English wheat and barley crops. Regardless, five years later, it was England's turn to escape apparently unscathed when serious dearth struck

[263] Campbell, *Three centuries*; Ludlow, 'Utility 2', 270.
[264] Ludlow, 'Utility 2', 270; Britton, 'Meteorological chronology', 157–8.
[265] Rydvale, '800 years'. The OWDA reveals wet spring–summer conditions across much of Ireland for 1425 (following a notably wet 1424) and neutral to quite dry conditions across much of Britain (following only a moderately wet 1424): Cook, 'Old World megadroughts'.
[266] Britton, 'Meteorological chronology', 158–9; Campbell, *Three centuries*.
[267] Campbell, *Three centuries*.

Ireland in the summer of 1433, although both countries experienced the long and hard winter that followed.[268]

By the second quarter of the fifteenth century the interval of relatively stable and benign weather conditions that followed the Wolf Solar Minimum and coincided with the Chaucerian Solar Maximum was effectively over. Thereafter, onset of the Spörer Solar Minimum initiated the first decisively cold phase of the so-called Little Ice Age (Fig. 1), characterised by cooler global and northern hemisphere temperatures. In the Scottish Cairngorms, summer temperatures were cooling from 1419 to 1441 (the coldest summer in over 200 years) and remained depressed until at least 1450.[269] Meanwhile, Ireland, along with much of northern Europe, experienced some notoriously cold winters.[270] In the aforementioned 1433–4, the rare phenomenon of frozen-over rivers and lakes, last explicitly reported in 1251, is again described in the Annals. So intense was the freezing that 'numerous herds of cattle and horses and people and pack-horses used to go upon the chief lakes of Ireland' (*Annals of Ulster*).[271] Wildfowl, however, suffered grievously and, although it is not mentioned, casualties among livestock customarily over-wintered out of doors may also have been heavy.[272] The following winter seems to have been as bad.[273] Even so, the annalists convey a stronger impression of the remarkable nature of these freezing winter conditions, which had much of Europe in their grip, than of the hardship they presumably inflicted upon society, other than that, for the duration of the frost, the ground was frozen too hard to be worked.[274] Nor is there any hint that serious subsistence problems resulted or mention of plague or other disease-related deaths.

At a European scale 'there seems to have been only one major famine in the fifteenth century (that of 1437–8, affecting central European countries as well

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[268] 1433 (*Annals of the Four Masters*, also *of Ulster* and *of Loch Cé*): 'There was a famine in the summer of this year, called, for a very long time afterwards, *samhra na mear-githne* [Summer of the Aberration], because no one used to recognise friend or relative, in consequence of the greatness of the famine': Ludlow, 'Utility 2', 271. 1433–4 (*Annals of Ulster*, also *of Loch Cé* and *of Connacht*): 'Great frost began at the end of this year (the year of the great frost); namely [it began] five weeks before Christmas and lasted to the end of seven weeks after. And numerous herds of cattle and horses and people and [pack-]horses used to go upon the chief lakes of Ireland. And great destruction was inflicted upon the fowl of Ireland during that frost and so on': Ludlow, 'Utility 2', 271–2. Britton, 'Meteorological chronology', 161. There is some doubt over the exact winter season in question in the Annals: 1433–4 or 1434–5 are both plausible, though consideration of the English evidence suggests 1433–4.

[269] Rydvale, '800 years'.

[270] Camenisch, 'The 1430s'.

[271] Ludlow, 'Utility 2', 271–2.

[272] Ludlow, 'Utility 2', 271–2.

[273] 1435 (*Annals of the Four Masters*): 'An unusual frost and ice occurred in this year, so that people used to traverse the lakes and rivers of Ireland on the solid ice': Ludlow, 'Utility 2', 272–4. The *Annals of Ulster* and a second entry in the *Four Masters* provide incidental corroboration of the severe conditions in 1434 when describing the evacuation for safekeeping of livestock and belongings over a frozen Lough Erne [County Fermanagh].

[274] *Annals of Connacht*: Ludlow, 'Utility 2', 271–2; Camenisch, 'The 1430s'.

as Britain)'.[275] Its trigger was a classic back-to-back harvest failure that stands out clearly in the English record of grain yields and prices (Fig. 10).[276] As was often the case, persistent and unseasonable cool and wet weather were to blame. Across Europe, this climate-related crisis was followed immediately by one of the most widely recorded of all fifteenth-century plague outbreaks, which strikingly illustrates the potential causal relationship between the two.[277] Intriguingly, if the testimony of Ireland's annalists is to be believed, Ireland, unlike neighbouring Scotland, was spared the famine but not the plague.[278] Thus, the Annals have nothing to say about either the weather or the harvests of 1437–8 but then, in the spring of 1439, the *Annals of the Four Masters* report 3,000 plague deaths in Dublin and the next year plague counted many notables in Connacht among its victims.[279]

In contrast to England, in Ireland the weather in the 1440s appears to have been worse and to have had more serious consequences than that in the 1430s. The decade was also conspicuously cold in the Scottish Cairngorms.[280] Respecting Ireland, the set of Gaelic Annals written by Gaelic scholar Dubhaltach Mac Fhirbhisigh in 1666 and spanning 1443 to 1468 is particularly informative.[281] They note the wetness of the summers of 1443 and 1444 and that the former proved good for fish but bad for bees and sheep and the latter 'made all corn maltish [i.e., fermented] for the most part'.[282] The next year witnessed heavy cattle mortality and the dearth of victuals and corn.[283] This was followed in 1446 by another 'hard year'.[284] The upshot of these four consecutive years of miserable weather was that by the spring of 1447 'all Ireland' was reduced to a state of hunger, whereby 'men were then wont to eat all manner of herbs for the most part'.[285] To make matters worse, plague broke out in both England and Ireland and raged throughout summer and autumn. In Ireland, the many who succumbed to the disease included, by repute, 700 priests (*Annals of the Four Masters*), who, as frontline workers, presumably often contracted plague when

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[275] Alfani and Ó Gráda, 'Famines in Europe', 8–9.
[276] Campbell, 'Grain yields on English demesnes', 152–5.
[277] Biraben, *Les hommes et la peste*, *vol. 1*, 363–74; Campbell, *Great Transition*, 314.
[278] Oram, 'Worst disaster', 231; Rydvale, '800 years'; https://celt.ucc.ie//published/T100005D/index.html (M1439.16).
[279] https://celt.ucc.ie/published/T100005D/index.html (M1440.1).
[280] Rydvale, '800 years'.
[281] 'The Annals of Ireland, from the Year 1443 to 1468'. The sheer density of entries in the 26 years covered by these Annals attests to the scope of recording undertaken by the Gaelic learned families, much of which is now lost. For the author (a.k.a. Duald Mac-Firbis or Dudley Firbisse), who also compiled the *Chronicon Scotorum*: Nollaig Ó Muraíle, *The celebrated antiquary Dubhaltach Mac Fhirbhisigh (c.1600–1671): his lineage, life and learning* (Maynooth, 2002, 2nd edition).
[282] 'The Annals of Ireland, from the Year 1443 to 1468', 207; Ludlow, 'Utility 2', 274–5.
[283] Ludlow, 'Utility 2', 275.
[284] Ludlow, 'Utility 2', 275.
[285] Ludlow, 'Utility 2', 275.

ministering to the sick and dying.[286] In a now established pattern, plague once again followed on the heels of bad weather and scarcity.

From this point, that plague continued to be widespread is attested by outbreaks in Meath and Armagh in 1448,[287] while further outbreaks and suggestive notices of possible plague deaths reappear variously in 1452, 1464–5, 1466 (wider outbreak), 1467, 1468 (wider outbreak), 1470 (wider outbreak) and 1471 (Fig. 2).[288] Other deadly diseases were also likely abroad.[289] From their descriptions, however, none appears to have been as devastating as the 1447 plague outbreak. Meanwhile, serious losses of cattle were noted in 1450 and 1473 and dearth recurred in 1450, 1461, 1462, 1465 and 1468.[290] Environmental instability was at a high level (Appendix 5) and weather extremes were common. The annalists, unaware that they were living at a time of depressed global temperatures and altered atmospheric circulation patterns, described 1450 as a 'hard warlike year… with many storms, and great loss of cattle'.[291] The spring and summer of 1462 were 'very hard', following a winter (presumably of 1461–2) characterised by a

[286] Biraben, *Les hommes et la peste*, *vol. 1*, 363–74; Lyons, 'Weather, famine, pestilence and plague', 69–70; Ludlow, 'Utility 2', 275; https://celt.ucc.ie//published/T100005D/index.html (M1447.2).

[287] 'A great plague raged in Meath, of which Conor, son of Hugh O'Farrell, Dermot Mac Conmaighe, and Henry Duv Mac Techedain, three friars of Longphort-Ui-Feargail, died' (*Annals of the Four Masters*): https://celt.ucc.ie//published/T100005D/index.html (M1448.1). In Armagh, plague led Archbishop Fey to conduct court proceedings outside the city: Anthony Lynch, 'Documents of Franciscan interest from the Episcopal Archives of Armagh 1265–1508', *Collectanea Hibernica* 31/32 (1989/1990), 9–102: 12.

[288] *Annals of the Four Masters*: https://celt.ucc.ie//published/T100005D/index.html (M1452.21; M1464.4-5, 7; M1467.15; M1468.9; M1471.3). *Annals of Connacht*: https://celt.ucc.ie/published/T100011.html (1464.2-4; 1464.11; 1464.13-14; 1464.53; 1465.13; 1466.28 (reportedly widespread: 'A great plague in Dublin, in Meath and in Leinster'); 1467.15; 1468.15; 1468.37 (reportedly widespread: 'There was great scarcity throughout Ireland this year, the result of plague, treachery(?), murder and general war); 1471.28-29). *Annals of Ulster*: https://celt.ucc.ie/published/T100001C/text093.html (U1470.3 ('Great plague, namely, Airaing, in Fermanagh this year and Ua Flannagain (that is, Cormac, son of Gilla-Isu) of Tuath-Ratha and many others that are not reckoned died thereof')).

[289] While both the *Annals of the Four Masters* and *of Connacht* often cite '*plaig*' for large outbreaks, readily translated as 'plague', many of the above-cited reports (see previous footnote) of individual deaths cite '*tregait*' as the underlying disease. O'Donovan renders these instances as 'plague' (perhaps on contextual grounds) in translating the *Four Masters*, while Freeman renders this 'colic' in translating *Connacht*. Crawford's coverage of this term ('Disease and illness', 208–11) considers examples reported in the Annals between the tenth and eleventh centuries, and hence, if the same as these fifteenth century instances, not bubonic plague. There is no definitive diagnosis, but, as Crawford notes, the term is often also associated with 'lumps' and 'gripping', in addition to 'colic'. Also note that the epidemic reported uniquely by the *Annals of Ulster* in 1470 cites 'airaing', left untranslated by Hennessy and MacCarthy.

[290] Ludlow, 'Utility 2', 276–9, 281.

[291] Ludlow, 'Utility 2', 276.

'great frost…that slaughtered many flocks of birds'.[292] Spring in 1465 was delayed by 'great frost and snow and stormy weather', and 1471 witnessed localised but destructive hail storms followed by a hot summer and very dry autumn.[293] They had only to read Gerald of Wales's *Topographia Hibernica* to discover how much more mild and temperate meteorological conditions had been in the 1180s.[294] Some of these problem years matched years of poor weather and deficient harvests in England, notably 1461, 1462 and 1465, but not all, for although the unsettled character of weather conditions at this time was general, the actual weather experienced in Ireland and England appeared often quite different. This is suggested in the significantly narrower rings displayed by English oaks between 1461 and 1468 compared with their Irish counterparts (Appendix 4) and the absence of much correlation between the two oak-ring series throughout the 1440s, 1450s and 1460s (Fig. 4).[295]

Ireland's agrarian economy, particularly in the Gaelic-dominated regions of the north and west most familiar to the annalists, was also less tillage based and more grass dependent than England's, which is no doubt why cattle mortalities were evidently of such concern.[296] Murrains, hard winters and deficiencies of winter pasture were more to be dreaded than cool and damp summers in places where dairy produce featured prominently in diets, and where wealth and status were measured in cattle. Given that cattle were typically over-wintered on standing herbage rather than fed on hay and that most were not housed, as Kenneth Nicholls notes, 'a severe winter and delayed spring could lead to a heavy mortality of cattle, with consequent famine'.[297] Back in the twelfth century Gerald of Wales had described how in Ireland 'The grass is green in the fields in winter, just the same as in summer', thereby highlighting the climatic characteristics that justified these methods of stock management.[298] Their economic rationale

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[292] 'Annals of Ireland 1443 to 1468': Ludlow, 'Utility 2', 277.

[293] 1465 (*Annals of Connacht*, also 'of Ireland 1443 to 1468'): 'Exceeding great frost and snow and stormy weather this year, so that no herb grew in the ground and no leaf budded on a tree until the feast of St. Brendan [16 May], but a man, if he were the stronger, would forcibly carry away the food from the priest in church, even though he had the Sacred Body in his hands and stood clothed in Mass-vestments'. 1471 (*Annals of Connacht*, also *of the Four Masters*): 'Showers of hail fell each side of Beltaine [1 May], with lightning and thunders, destroying much blossom and beans and fruits in all parts of Ireland where they fell…'; (*Annals of Ulster*) 'A hot summer this year'; (*Annals of Connacht*) 'An abundant nut-crop this year; the summer and autumn very dry and all the crops very early'. Ludlow, 'Utility 2', 278–80.

[294] Gerald of Wales, *History and topography of Ireland*, 34–5, 53–4.

[295] The correlation coefficient of the ring widths of Irish oaks to southern English oaks from 1440 to 1470 is +0.007 (between 1240 and 1270 it is +0.616).

[296] Katharine Simms, 'Gaelic culture and society', in Smith (ed.), *Cambridge history of Ireland*, *vol. 1*, 415–40: 417–18.

[297] Kenneth W. Nicholls, *Gaelic and Gaelicized Ireland in the middle ages* (Dublin, 2003, 2nd edition), 137.

[298] Gerald of Wales, *History and topography of Ireland*, 53.

lay in the calculation that the costs of the losses inflicted by occasional extreme winters were less than those of investing scarce capital in housing animals and scarce labour in making hay (itself problematic in a rainy climate), especially if byres, barns and ricks were liable to become the targets of violent and destructive attacks.

In the thinly peopled countryside of the north and west, where cattle raiding and rustling were endemic, there were sound socio-economic as well as environmental reasons for practising a form of transhumance and removing cattle to higher or less fertile grounds in the summer months of strongest grass growth and then returning them for the winter to more sheltered or fertile pastures to graze upon the accumulated summer grass as foggage.[299] Elsewhere, from the mid-fourteenth and into the fifteenth century, the shrinking labour force in combination with the expansion of the area under pasture encouraged wider adoption of these practices. Combined with the greater general resilience of pastoral agriculture to cool and wet conditions, the 'Gaelicisation' of agriculture in much of the previous English Lordship, alongside the evolution of hybrid farming systems that employed haymaking and winter housing to provide greater security against winter cold, can be seen as rational adaptations to the evolving climatic, economic and cultural contexts.[300]

Adopting these extensive methods of agriculture made sense in a situation where land was increasingly abundant and labour scarce, as, by the mid-fifteenth century, had been the case for more than a hundred years. Their corollary was that, until at least the 1440s, as the Belfast dendrochronological database indicates (Fig. 5), oak woodland was actively regenerating as demographic pressure upon woodland resources remained weak. By implication, Ireland's population was now reduced to a very low ebb, with average densities probably less than half those of its pre-1315 peak. It was as well that per capita landed resources were now available in relative abundance, because, as documented by the Annals and discussed above, society was exposed to significant climatological and epidemiological stress during these middle years of the fifteenth century. In Fig. 1 the decades of the 1440s to the 1460s stand out as one of the most distinctive episodes on palaeoclimatic record, when a duo of major tropical eruptions (in 1452 and 1457) coincided with weak solar forcing at the nadir of the Spörer Solar Minimum.[301] Further volcanic forcing

[299] On foggage: Ó Corráin, 'Ireland *c*.800: aspects of society', 571–2. On a modified transhumance as a cultural adaption: Keleman, 'Indigenous agriculture', 206–8. For the continuation of such arrangements deep into the Little Ice Age in the seventeenth century: Gerard Boate, *Ireland's natural history. Being a true and ample description of its situation, greatness, shape, and nature*… (London, 1652), 174.

[300] Nicholls, *Gaelic and Gaelicized*, 137; Seán Duffy, 'The problem of degeneracy', in James Lydon (ed.), *Law and disorder in thirteenth-century Ireland: the Dublin parliament of 1297* (Dublin, 1997), 87–106: 103–4.

[301] 1452 (VSSI of 9.97 Tg) and 1457 (VSSI of 32.98 Tg): Toohey and Sigl, 'Volcanic stratospheric sulfur injections'.

then followed from a closely timed trio of northern hemisphere extratropical eruptions in 1470, 1477 and 1480.[302] Collectively, these forcings can be credited with initiating and reinforcing a general lowering of global and hemispherical mean temperatures and an associated reconfiguration of atmospheric circulation patterns.[303] Hence the persistent weakness of the NAO, the occasional Arctic winters and cool summers, and elevated level of environmental instability experienced by Ireland at this time, following more than a hundred years of fairly relentless demographic and economic contraction, political readjustment, and concomitant social and cultural change. These fifteenth-century weather conditions stand in stark contrast to those that had prevailed almost 300 years earlier, when the Medieval Solar Maximum was at full strength, the NAO was predominantly positive, environmental instability was more muted, the high-medieval demographic and economic boom was in full swing, and woodland almost everywhere was in retreat.

Post 1450—low-level equilibrium

By the second half of the fifteenth century Irish society was almost back at the stage it had been in the mid-eleventh century: people were scarce, in per capita terms land was relatively abundant, and, after a century of regeneration, oak woodland was becoming plentiful (Fig. 5).[304] Eventually, however, building in oak resumed on a modest scale. From the 1420s tower houses were erected in growing numbers, almost fifty new friaries were founded (numbers of them in the south and west of Ireland), many of the older monasteries were remodeled, often on a reduced scale, and, in the more important towns, existing churches were added to and embellished.[305] This building revival, however, was altogether less dramatic than the construction boom which had taken off with such dynamism 400 years earlier and then been lent added momentum by the English invasion and settlement. Its mainsprings were the ending of population decline and settlement retreat, some abatement of endemic levels of violence, and the establishment of a degree of political and social stability adapted to the altered economic and environmental circumstances then prevailing.

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[302] Individually small to moderate, this trio is notable for its clustering within a decade, with VSSI of 1.39 Tg for 1470, VSSI of 5.12 Tg for 1477 and VSSI of 1.66 Tg for 1480: Toohey and Sigl, 'Volcanic stratospheric sulfur injections'.

[303] Campbell, *Great Transition*, 335–49.

[304] Kaplan, Krumhardt and Zimmermann reckon that woodland's share of agriculturally usable land increased by over two-thirds during the half-century or so that followed the Black Death: Kaplan, Krumhardt and Zimmermann, 'Prehistoric and preindustrial deforestation', 3023.

[305] H.G. Leask, *Irish castles and castellated houses* (Dundalk, 1977), 75-124; H.G. Leask, *Irish churches and monastic buildings, vol. 3, medieval gothic the last phases* (Dundalk, 1978); S.G. Ellis, *Tudor Ireland: crown, community and the conflict of cultures 1470–1603* (London and New York, 1985), 39–40; Moss, 'Material culture', 485–90.

Although there are signs that in England demographic replacement rates were fitfully edging upwards during the final decades of the fifteenth century,[306] in Ireland disease appears to have remained a significant burden. The great plague (*pladh mor*) of 1470 is reported as an outbreak of '*airaing'* by the *Annals of Ulster*, a case of what may have been smallpox ('*galar breac'*) is noted by the *Annals of Loch Cé* (also *of Connacht*, *of Ulster* and *of the Four Masters*) in 1488, and four years later the *Annals of Ulster* record the notable death of James Fleming, Baron of Slane, from the 'English sweat'.[307] Plague itself had returned with outbreaks in 1478 and in 1488, continuing into 1489, for which year the *Annals of the Four Masters* reported great numbers dying of a 'great plague' (*pláigh mhór*) 'so devastating that people did not bury the dead throughout Ireland'.[308] Not unusually, reports of plague in the Annals follow reported plague outbreaks in England with a one- or two-year lag, which implies that the disease was often sustained by repeated ship-borne reintroduction from either England or Europe.[309] The introduction of plague to north-west Ulster in 1478 via the minor west-coast port of Assaroe demonstrates that a single infected ship was all that was required to ignite an outbreak.[310] For that reason the country's port towns and their hinterlands were especially susceptible, with Dublin, on the evidence of the Annals, not unusually the epicentre of Irish plague outbreaks. Reports of plague outbreaks in the Annals only finally slacken over the course of the sixteenth century.

More positively, there appears to have been some easing of overall levels of violence, for violent actions and events loom (proportionately) less prominently in the Annals, and D.B. Quinn considers that 'under screens of defence of one kind or another, most parts of late-fifteenth century Ireland, both Gaelic

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306 Broadberry, *British economic growth*, 15–20; Campbell, *Great Transition*, 351–5.

307 Ludlow, 'Utility 2', 279, 282–3, 285–7. As bemoaned by J.F.D. Shrewsbury (*A history of the bubonic plague in the British Isles* (Cambridge, 1970), 154), '*airaing*' in 1470 is left untranslated by Hennessy and MacCarthy. Guy Thwaites, Mark Taviner, and Vanya Gant, 'The English sweating sickness, 1485 to 1551', *New England Journal of Medicine* 336 (1997), 580-2.

308 1478: below, note 312. 1488 and 1489 (when the *Annals of Ulster* and *of the Four Masters* additionally report many individual plague deaths): Ludlow, 'Utility 2', 282–3, 285–7.

309 Biraben, *Les hommes et la peste*, *vol. 1*, 363–74; Lyons, 'Weather, famine, pestilence and plague', 71–2.

310 *Annals of Ulster*, 1478: https://celt.ucc.ie//published/T100001C/index.html (U1478.6). Also in the *Annals of the Four Masters*: https://celt.ucc.ie//published/T100005D/index.html (M1478.11) and (under 1477) in the *Annals of Loch Cé*: https://celt.ucc.ie//published/T100010B/index.html (LC1477.4). The provenance of the ship is not stated, although by the late-fifteenth century Ireland's west-coast ports were visited by merchant vessels from both Bristol and Spain: Wendy Childs and Timothy O'Neill, 'Overseas trade', in Cosgrove (ed.), *New history of Ireland, vol. 2*, 492–524: 504–5; Michael Bennett, 'Late medieval Ireland in a wider world', in Smith (ed.), *Cambridge history of Ireland, vol. 1*, 329–52: 348–9.

and Anglo-Irish, were prospering'.[311] That prosperity, however, was shallow and unevenly spread and the bulk of the country's small population lived in material poverty. Bioarchaeological evidence from the graveyard at Ballyhanna, near Ballyshannon, Co. Donegal, reveals a late-medieval predominantly Gaelic population characterised by poor life expectancy, nutrition and health.[312] In a country where power was so fragmented and personalised, peace and improved security were essential preconditions for demographic and economic recovery: when that began it must have done so as a piecemeal process dependent upon favourable local political circumstances. Meanwhile, developments in maritime technology were creating the potential for a sea-borne commercial revival, in which Ireland was geographically well placed to participate. Nevertheless, while European bullion supplies remained scarce and access to the Orient was obstructed by the emergent power of the Ottomans, there was little prospect of Ireland becoming swept up in the momentum of another continent-wide commercial revolution.[313] That would be delayed until the second half of the sixteenth century or, indeed, later.[314]

As the English author of the *Libelle of Englyshe polycye* acknowledged, mid-fifteenth century Ireland was endowed with an array of natural resources in relative abundance.[315] What was deficient, while international commerce remained slack, domestic demand limited and labour scarce, were the incentives to exploit them more intensively. By 1500, Dublin, still probably the largest Irish town, had a population of less than *c*.8,000, down from *c*.11,000 in 1290, and the share of the population living in towns of all sizes had also probably shrunk.[316]

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[311] D.B. Quinn, 'Aristocratic autonomy, 1460–94', in Cosgrove (ed.), *New history of Ireland, vol. 2*, 591–618: 597; Ellis, *Tudor Ireland*, 39–40.

[312] Catriona McKenzie and Eileen Murphy, 'Health in medieval Ireland: the evidence from Ballyhanna, Co. Donegal', in Sheelagh Conran, Ed Danaher and Michael Stanley (eds), *Past times, changing fortunes* (Dublin, 2011), 131–43. The bulk of the skeletons date from 1200 to 1650 CE: C.J. McKenzie and E.M. Murphy, *Life and death in medieval Gaelic Ireland: the skeletons from Ballyhanna, Co. Donegal* (Dublin, 2018), 9–12.

[313] Campbell, *Great Transition*, 332–5, 364–73, 388–92.

[314] W.J. Smyth, *Map-making, landscapes and memory: a geography of colonial and early modern Ireland c.1530–1750* (Cork, 2006), 345–450; Raymond Gillespie, 'Economic life, 1550–1730' in Jane Ohlmeyer (ed.), *The Cambridge history of Ireland, vol. 2, 1550–1730* (Cambridge, 2018), 531–54; Francis Ludlow and Arlene Crampsie, 'Environmental history of Ireland, 1550–1730', in Ohlmeyer (ed.), *Cambridge history of Ireland, vol. 2,* 608–37: 611–13.

[315] The list of commodities comprises woollen and linen cloth and frieze; fells and fleeces of sheep, lambs and kids, cattle hides, harts' hides and 'other hides of venery', marten furs and the pelts and skins of rabbits, hares, foxes, squirrels and otters, and fish (salmon, hake and herring); all except cloth were the products of grazing, hunting, trapping and fishing: G. Warner (ed.), *The libelle of Englyshe polycye: a poem on the use of sea-power 1436* (Oxford, 1926), 34–6.

[316] H.B. Clarke, *Dublin, part I, to 1610*, Irish Historic Towns Atlas 11 (Dublin, 2002), 12. Available population estimates for Dublin are discussed in Murphy and Potterton, *Dublin region in the Middle Ages*, 30–1. For the numbers and sizes of Irish towns in 1290: Campbell, 'Benchmarking medieval economic development', 931.

Away from the handful of modestly prosperous walled coastal ports, urban demand was therefore of little consequence in shaping land-use and promoting agricultural specialisation. At a national scale, the country's low urbanisation ratio is symptomatic of economic underdevelopment and, by contemporary standards, of relatively low gross domestic product (GDP) per head.[317] Society therefore remained materially poor and overwhelmingly rural and agrarian; hence the paradox that, amidst seeming plenty, Ireland's population remained susceptible to weather-induced output failures. Fortunately, during the final decades of the fifteenth century few of these risks appear to have materialised.

In the absence of further significant volcanic forcing and as the Spörer Solar Minimum ended and the output of solar irradiance rose, environmental instability slowly subsided from its peak in the 1450s (Fig. 1 and Appendix 5). From the 1470s the NAO was back to close to normal strength and precipitation and temperatures had both recovered to near their long-term averages (Appendices 1–3). Once the difficult 1460s had passed, the worst years according to the Annals were 1478 and 1487. The first, a plague year, followed a VSSI of 5.12 Tg from a northern-hemisphere extratropical eruption the previous year and began with 'a mighty wind' on the the eve of the Epiphany [6 January] which 'laid low' 'men, cattle, trees, lake and land buildings…throughout Ireland'.[318] The rest of the year provided almost ideal growing conditions for Irish oaks, whereas according to the *Annals of Connacht*, *of Ulster*, *of Loch* Cé and *of the Four Masters* it was 'a hard, niggardly year' for crops.[319] As already noted, it was also a plague year.[320] Conditions were similar in 1487, with a 'great wind' on 24 February 'whereby many houses and churches were unroofed' and trees broken and then 'great inclemency of rain in the summer of this year, like a winter of inclemency, so that much of the crops of Ireland was destroyed thereby'.[321] More happily, 1471 (also following a northern hemisphere eruption—VSSI of 1.39 Tg—the previous year) was remembered for its hot summer, dry autumn

[317] On the positive association between urbanisation ratios and estimates of GDP per head in late-medieval Europe: B.M.S. Campbell, 'National incomes and economic growth in pre-industrial Europe: insights from recent research', *Quaestiones Medii Aevi Novae* 18 (2013), 167–96: 170–2.

[318] Lyons, 'Weather, famine, pestilence and plague', 71–2; Toohey and Sigl, 'Volcanic stratospheric sulfur injections'; (*Annals of Connacht*, also *of Ulster*, *of Loch* Cé, and *of the Four Masters*) Ludlow, 'Utility 2', 282–3. The summer of 1477 stands out as especially cold in the Scottish Cairngorms (Rydvale, '800 years') and both 1477 and 1478 are quite dry in the OWDA (Cook, 'Old World megadroughts').

[319] Lyons, 'Weather, famine, pestilence and plague', 71–2; Ludlow, 'Utility 2', 284.

[320] Above, p. 230.

[321] Lyons, 'Weather, famine, pestilence and plague', 71–2; 1487 (*Annals of Ulster*): Ludlow, 'Utility 2', 284. 1488 appears exceptionally wet across Ireland in the OWDA (Cook, 'Old World megadroughts').

and early harvest.[322] There would not be a summer as good from the perspective of the annalists for another 21 years.[323]

It was the 1490s that brought the most testing weather. Conditions were particularly bad in 1491, 'called by the natives the Dismal Year, by reason of the continual fall of rain all the summer and autumn'.[324] The year began with a blast of Arctic cold admitted by a weak NAO; in Burgundy a cool summer delayed the Pinot Noir grape harvest, and in Ireland persistent wet weather ruined that year's harvest.[325] This ensured that a great famine (*Ascalt mor a n-Erinn*) followed in 1492, which was also, as noted by the *Annals of Ulster*, memorable for its hot summer.[326] The first of three consecutive years of drought, it was a conspicuously narrow-ring year for oaks in Ireland as across Europe.[327] By 1494 or early 1495, wheat and beef were sold at elevated prices in Drogheda.[328] Worse was to follow: in 1496 (a wide-ring year for oaks, implying abundant spring–summer precipitation) a 'great inclemency' of weather prevailed.[329] This brought

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[322] Toohey and Sigl, 'Volcanic stratospheric sulfur injections'. 1471 (*Annals of Ulster*): Ludlow, 'Utility 2', 279. The *Annals of Connacht* usefully add 'An abundant nut-crop this year; the summer and autumn very dry and all the crops very early'. The OWDA confirms moderate spring–summer dryness this year (Cook, 'Old World megadroughts').

[323] 1492 re. 1471 (*Annals of Ulster*): 'A hot summer this year; to wit, a year and twenty since the hot summer before': Ludlow, 'Utility 2', 285.

[324] 'William Wilde's table of Irish famines', 7.

[325] Ortega, 'Model-tested North Atlantic Oscillation reconstruction'. Isabelle Chuine *et al*., 'Burgundy grape harvest dates and spring–summer temperature reconstruction' (2005), IGBP PAGES/World Data Center for Paleoclimatology Data Contribution Series, NOAA/NCDC Paleoclimatology Program, Boulder CO, USA # 2005-007, http://www.ncdc.noaa.gov/paleo/paleo.html. Ludlow, 'Utility 2', 285: 1491 (*Annals of Ulster*, also *of the Four Masters*): 'Great inclemency of wetness during the greater part of the summer of this year and the self-same in harvest of the same year, so that likeness to the extent of the inclemency was not found since the Deluge poured upon the world, so that the corn of all Ireland, save a little, failed and particularly in Fermanagh' [this year the OWDA appears in rare contradiction to the Annals, with spring–summer 1491 registering notably dry (Cook, 'Old World megadroughts')]. The *Annals of Ulster* also report a major windstorm, though without explicitly associated impacts. Summer 1491 was cold in Scotland: Rydvale, '800 years'.

[326] 'William Wilde's table of Irish famines', 7; Lyons, 'Weather, famine, pestilence and plague', 72; 1492 (*Annals of Ulster*): 'Great famine in Ireland this year': Ludlow, 'Utility 2', 285.

[327] Cook, 'Old World megadroughts'.

[328] Reported under 1494, but using Annunciation ('Old Style') dating, meaning that these conditions may also pertain to the first months of 1495 (up to 24 March): Diarmuid Mac Iomhair, 'Two old Drogheda chronicles', *Journal of the County Louth Archaeological Society* 15:1 (1961), 88–95: 92.

[329] Confirmed by the OWDA, with a notably wet spring–summer in 1496: Cook, 'Old World megadroughts'. In Dublin the River Poddle caused serious flooding: J.H. Bernard, 'Calendar of documents contained in the chartulary commonly called "*Dignitas decani*" of St Patrick's Cathedral', *Proceedings of the Royal Irish Academy* 25C (1904–5), 481–507: 491; Peter Crooks (ed.), *A calendar of Irish chancery letters, c. 1244–1509*, Patent Roll 11 Henry VII, §30: https://chancery.tcd.ie/document/patent/11-henry-vii/30.

'enormous destruction on beeves and on other cattle also' and inflicted 'great dearth [on] the greater part of Ireland … and great hindrance on the husbandry of the year … whereby everyone in general was ruined in his crops'.[330] This led in 1497 to a 'very great, grievous famine throughout all Ireland … to which the folk of this time saw not the equal, nor like; for there was scarce an angle or recess in all Ireland wherein died not many persons of that hunger'.[331] Faced with starvation, according to the *Annals of the Four Masters*, 'people ate of food unbecoming to mention, and never before heard of as having been introduced on human dishes', with these desperate conditions persisting into 1498.[332] The language of the Annals leaves little doubt of the magnitude and severity of this event which unfolded over a Biblical seven years.

The run of adverse meteorological conditions that triggered the 1497–8 food crisis had more to do with bad luck than any specific forcing event or climate anomaly. No volcanic eruption was culpable and all fell within the statistical norms of Ireland's variable maritime climate. Nor was this in any sense a 'Malthusian crisis', for the population had shrunk to no more than 0.75 million and resources per head were abundant.[333] That, on the testimony of the Annals, so many should have been affected so grievously therefore bears witness to Irish society's lack of resilience to weather-induced output shortfalls at this time: storage was limited, wealth polarised, charity localised and unequal to the scale of the challenge, organised relief effectively absent and faith in divine intervention too blind.[334] On this occasion, agricultural production systems well adapted to the climatic norm fell disastrously short when confronted by a close succession of far-from-unprecedented meteorological extremes. The conditions of 1497–8 can thus be posited as a famine borne not from overpopulation but from underdevelopment. In this sense, the famine of 1497–8 and many others beforehand can also be more clearly seen as a failure of production than of distribution.[335]

Only by evolving more effective institutions of government and administration, developing more efficient markets and networks of distribution,

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[330] 'William Wilde's table of Irish famines', 7; 1496 (*Annals of Ulster*): Ludlow, 'Utility 2', 287.

[331] 'William Wilde's table of Irish famines', 7; Lyons, 'Weather, famine, pestilence and plague', 72–3. 1497 (*Annals of Ulster*, also *of Loch Cé*, *of Connacht*, and *of the Four Masters*): Ludlow, 'Utility 2', 288.

[332] Ludlow, 'Utility 2', 288.

[333] Raymond Gillespie, *The transformation of the Irish economy, 1550–1700* (Dundalk, 1991), 12–3.

[334] For comment on how adaptation to extremes may be hampered by a belief in divine intervention: J. Haldon *et al*., 'Demystifying collapse: climate, environment, and social agency in pre-modern societies', *Millennium* 17:1 (2020), doi: 10.1515/mill-2020-0002. Also, Ludlow and Travis, 'STEAM approaches to climate change', 56–8.

[335] Guido Alfani and Cormac Ó Gráda, 'The timing and causes of famines in Europe', *Nature Sustainability* 1 (2018), 283–8.

investing in the infrastructures of transport and storage, diversifying economic output, raising levels of agricultural productivity and putting in place practical welfare measures—achievements that did follow in later centuries—would society slowly escape the tyranny of the weather. In these respects, at this midway point in the second millennium, Irish society was little more advanced than it had been at the beginning of that millennium when it had been hit so hard by the scarcities of 1004 and 1047. At no point during the intervening centuries had it enjoyed sufficient food security to withstand the potentially harmful effects of sustained runs of adverse meteorological conditions or individual extremes of great (but not necessarily exceptional) magnitude. Late-medieval Ireland was a country inescapably in thrall to episodic subsistence crises, the worst of which escalated into famines displaying many or all of the attributes itemised by Cormac Ó Gráda as characteristic of such catastrophes.[336]

Conclusion—extreme weather, famine, violence and plague in late-medieval Ireland

Gerald of Wales's characterisation of Ireland's temperate and healthy, wet and windy, climate as essentially extreme free is belied by the testimony of the Annals.[337] Over the 500 years surveyed in this paper, they record rivers and lakes frozen so hard that flocks and herds could pass over them, summers so hot and droughts so severe that the River Shannon could be forded on foot, harvest seasons that were a washout, floods that swept away bridges, mills and houses, lightning strikes that ignited and destroyed buildings, hail storms with stones the size of crab apples, and great winds that toppled steeples and sank ships.[338] None of this should be a surprise, for Ireland's climate is also marginal in terms of its exposure to fluctuations in the rival strengths of maritime and continental, Atlantic and Arctic, pressure systems as mediated by solar and volcanic forcing and the internal dynamic of the multidecadal Atlantic climate variability.[339] Also, all climates are capable of throwing up random extremes and Ireland's is no exception. Its annalists plainly took grim and sometimes even moralising delight in recording those freak meteorological events responsible for bizarre deaths, as in 1134 when the *Annals of Tigernach* recorded that 'the Kindred of Eoghan of Tulach Óc conspired against Mael Maedhóig and a flash of lightning consumed twelve men of them on the spot where they conspired against him'.[340] Or in 1177 when the same Annals described 'a mighty outbreak of water, for greatness resembling a mountain, [that] went through the midst of Glendalough [Co. Wicklow], carried away the bridge and mill of the town and left some of its fish amid the town. Then it entered Inbhear Mór [Arklow, Co. Wicklow], drowned

[336] Ó Gráda, *Famine*, 7; above, note 127.
[337] Gerald of Wales, *History and topography of Ireland*, 34–5, 53–4.
[338] As exemplified above and abundantly detailed in Ludlow, 'Utility 2'.
[339] Jianglin Wang *et al*., 'Internal and external forcing of multidecadal Atlantic climate variability over the past 1,200 years', *Nature Geoscience* 10:7 (2017), 512–17.
[340] Ludlow, 'Utility 2', 179–80.

the fisherman, and swept his net into the sea'.[341] In both cases the victims were unlucky enough to be in the wrong place at the wrong time.

Nevertheless, intervention by the weather to overtly facilitate or shape the course and outcome of major historical events was altogether more exceptional.[342] That was the case in a small way during the bitter winter of 1433–4 when the inhabitants of Fermanagh were able to escape from an army led by the O'Neill by fleeing westwards with their cattle and moveables across an ice-bound Lough Erne.[343] More crucially, it is interesting to speculate what the counterfactual of the ill-timed Scottish invasion of 1315–18 might have been, and what direction Irish history might consequently have taken, had the attempted conquest not coincided so exactly with the worst years of the Dantean Anomaly.[344] As it was, the devastating combination of war, bad weather and back-to-back harvest failure, followed within three years by the rinderpest panzootic, ensured that the famine of 1315–18 was one of the greatest, if not the greatest, to have afflicted late-medieval Irish society.[345] Moreover, largely because of the reinforcing effect of the Bruce invasion, it stands out as perhaps the only late-medieval famine to have had an unambiguously enduring historical impact.

Famines—*gorta, gorta mór*—punctuate the record of the Annals and are the most explicit demonstration of the negative impact that extreme weather could have upon Irish society. What exactly Ireland's annalists meant by the term *gorta* they do not define but from the contexts in which it appears it was clearly intended to convey the extreme hardship that arose from acute hunger and starvation, with all the desperate nutritional, economic and criminal measures to which its victims might resort. Thus, the *Chronicon Scotorum* provides an unusually graphic description of one such famine in 1116: 'Great famine [*Gorta mor*] in the spring so that a man would sell his son and his daughter for food and men would even eat one another, and dogs'.[346] Modern definitions of famine are tighter. Specifically, Ó Gráda has defined famine as 'A shortage of food or purchasing power that leads directly to excess mortality from starvation or

[341] Ludlow, 'Utility 2', 194.

[342] For later examples of such interventions: Ludlow and Crampsie, 'Environmental history of Ireland, 1550–1730', 627–36; and Francis Ludlow and Arlene Crampsie, 'Climate, debt and conflict: environmental history as a new direction in understanding early modern Ireland', in Sarah Covington, Vincent Carey and Valerie McGowan-Doyle (eds), *Early modern Ireland: new sources, methods, and directions* (London, 2019), 269–300: 278–90.

[343] Ludlow, 'Utility 2', 272–4.

[344] McNamee, *Wars of the Bruces*, 166–205.

[345] The costs in the Dublin region of wet weather and flooding, opportunistic Gaelic raiding, and the burden of sustaining the king's forces in transit to fight the Scots are reflected in detail in Crooks, *Calendar of Irish chancery letters*, Close Role 9 Edward II, §1 (16 December 1315): https://chancery.tcd.ie/document/close/9-edward-ii/1. For the impacts of harvest failure, devastating Scottish raids and rinderpest upon northern England: Ian Kershaw, *Bolton Priory: the economy of a northern monastery 1286–1325* (Oxford, 1973); McNamee, *Wars of the Bruces*, 72–122.

[346] Ludlow, 'Utility 2', 173–4.

hunger-induced diseases'.[347] Of the many famines reported in the Annals only a minority unequivocally meet the criterion of excess mortality on the basis of the descriptions given.[348] One such is that reported in the *Annals of Loch Cé* for 1227: 'a great famine in this year; and people died of it'.[349] The number that died, however, is never indicated. In a rare entry for 1271, the *Annals of Inisfallen* state that 'multitudes of poor people died of cold and hunger'.[350] Another for 1497 in the *Annals of Ulster* says 'there was scarce an angle or recess in all Ireland wherein died not many persons of that hunger'.[351] In two cases alone between 1000 and 1500 CE, specifically the famines of 1116 and 1315–18, the annalists state that the starving populations made resort to cannibalism, which, irrespective of whether it was true, reveals that in the minds of the annalists these were particularly terrible events when normal taboos and moral scruples were abandoned.[352]

Famine is often regarded as a symptom of Malthusian demographic pressure upon scarce resources, but it is difficult to interpret any of late-medieval Ireland's subsistence crises and famines in such narrowly economic terms. In fact, when famine struck Ulster in 1004 and 1047 and Ireland in 1497, the fundamental problem may have been more a deficit than a surfeit of people.[353] The crises of 1270–1, 1294–6 and 1315–18 alone coincide with the period when Ireland's population may have risen to a historically modest total of around 1.25 to 1.5 million and when, on the evidence of the oak dendrochronology dataset (Fig. 5), available landed resources were coming under pressure.[354] But the deteriorating political, fiscal and military situation in the English Lordship was also a significant contributing factor. Rather, insofar as famine in late-medieval Ireland had a common denominator, it was the negative impact of extreme weather (particularly in back-to-back years) upon agricultural production, often to the detriment of arable output, sometimes to that of pastoral output (especially when hard winters depressed grass growth or access to foggage and sent livestock mortality soaring), and occasionally to both. Thus, in 1115–16 and again in 1294–6

[347] Ó Gráda, *Famine*, 4; also, Alfani and Ó Gráda, *Famine in European history*, 2.
[348] Cormac Ó Gráda, 'Ireland', in Alfani and Ó Gráda, *Famine in European history*, 166–84, omits systematic discussion and evaluation of the annalistic record of Irish famines.
[349] Ludlow, 'Utility 2', 212–3.
[350] Ludlow, 'Utility 2', 236.
[351] Ludlow, 'Utility 2', 288.
[352] Ludlow, 'Utility 2', 173–4, 244–53; Ó Gráda, *Eating people is wrong*, 14–16, 26. The same trope was used in four separate chronicles for 700 CE, as in the case of the *Annals of Clonmacnoise* (a.k.a. *Mageoghagan's Book*): 'There was such famine and scarcity in Ireland for three years together, that men and women did eat one another for want': Ludlow, 'Utility 2', 60–2.
[353] Above, pp. 179, 182, and 233–4.
[354] Alfani and Ó Gráda ('Timing and causes', 283) make the general point that in Europe 'up to 1710, the main clusters of famines occurred in periods of historically high population density'.

it was grain-growing Leinster that appears worst affected, whereas in 1203 and 1227 famine was widely reported by annals with a focus on Clonmacnoise and Connacht, which implies that the grazing districts of the Shannon valley and east Connacht were experiencing difficulties. Similarly, in 1433 the *Annals of Loch Cé*, *of the Four Masters* and *of Ulster* all carried reports of the summer of scarcity in regions that were predominantly pastoral.

The recorded experience of food scarcity is, of course, chronologically uneven, not least because some periods were climatically more unsettled than others and the patterns of atmospheric circulation that determined Ireland's weather changed over time (Fig. 1). The available annalistic coverage is also intrinsically uneven, in terms of survival and the attention paid to extreme weather events and their repercussions for humans by individual annalists (Fig.2). Consequently, absence of any mention of food crises, as most conspicuously for the 60 years from 1339 until 1397, does not necessarily mean that none occurred, unless in this case the better wages and improved living standards that followed the Black Death provided some respite.[355] Certainly, at no point does late-medieval Ireland appear to have escaped more than temporarily from a state of chronic food insecurity, as evidenced by the recurrence of famine in 1203, 1227, 1236, 1263 and 1270–1 during a period that was otherwise favourable to demographic and commercial expansion (Fig. 6). War was certainly an important contributory factor, especially given that from the outset the English Lordship had a contested military border, aggressively expanding until the late-thirteenth century and contracting thereafter.[356] The nutritional deficiencies sustained by those repeatedly exposed to such food crises is writ large in the stunted and malnourished skeletons excavated from the late-medieval graveyards at Ballyhanna, Co. Donegal, and Ardreigh, Co. Kildare.[357] Dearth was the periodic lot of all those who made up the humble majority and when conditions were at their worst and dearth escalated into famine, mortality evidently soared. As recorded by the Annals, those faced with starvation typically resorted to desperate measures: flight (that could itself engender conflict and the spread of infection), the selling off of assets (including children into slavery), trading down to substitute and sub-standard foodstuffs and, for those with the weapons and audacity, theft, rustling, plunder and pillage.

It did not help that from the late-twelfth to the early-fourteenth centuries the weather in Ireland and England was so closely synchronised that years

[355] An order dated 26 August 1349 to the mayor and bailiffs of Dublin is certainly concerned that 'working men and servants' might, as in England, seek to work only 'for excessive wages' following the first onset of the Black Death, and should be penalised in such cases: Crooks, *Calendar of Irish chancery letters*, Close Role 23 Edward III, §17: https://chancery.tcd.ie/document/close/23-edward-iii/17.

[356] For example, the 1227 famine as it pertained to Connacht: Finan, *Landscape and history*.

[357] McKenzie and Murphy, 'Health in medieval Ireland'; McKenzie and Murphy, *Life and death in medieval Gaelic Ireland*, 394–401.

of scarcity in Ireland typically coincided with problem years in England. Since England was Ireland's nearest source of relief grain supplies, this meant that it was least able to supply them when Ireland's need was greatest. Worse, in common crisis years the greater pulling power of the more commercialised and monetised English market, coupled, during England's Welsh, Scottish and French wars, with heavy demands from the royal purveyors for victuals to provision the king's armies overseas, may have caused the normal net exodus of grain, meat and butter from Ireland to persist and what little came in the opposite direction is likely to have remained within the confines of Ireland's port towns, thereby providing scant relief to those in the country's rural interior.[358] At such times the prospects of Ireland receiving substitute food supplies from elsewhere were negligible and society had to get by on whatever, domestically, was available.

De facto, the food crises and famines that punctuate Ireland's late-medieval history underline the want of resilience that might have prevailed had there been greater solidarity between Gaels and Galls, more effective central government, heavier investment in storage facilities and transport infrastructures, more extensive market arbitrage and integration, fuller involvement and greater security in international trade and diplomacy, more generous endowment of charitable institutions, mature land and credit markets, and greater diversification of economic output.[359] Remedies to shortage were not absent but they were imperfectly and unevenly developed and too easily undone by political breakdown. Whatever resilience society may have possessed was also likely to be wholly undermined by the calamity of war, with its demands for manpower and pre-emptive claims on scarce revenues and provisions, threat to law and order, and destruction of capital goods, productive capacity and dis-inducement to investment.[360]

Personal violence, raiding, rustling and pillaging, war and invasion all loom large in the history of late-medieval Ireland and were fostered from 1169 by the intrinsic divisions between Gaels and Galls, the fragmented and personalised

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[358] Between 1280 and 1300 the limited available price evidence indicates that 'wheat prices in Dublin moved in a similar way to those in England' but with a premium in most years in favour of England: Murphy and Potterton, *Dublin region in the middle ages*, 478.

[359] In England, government efforts to alleviate food crises began in response to the Great Northern European Famine, 1315–7, in the reign of Edward II: Buchanan Sharp, 'Royal paternalism and the moral economy in the reign of Edward II: the response to the Great Famine', *Economic History Review* 66:2 (2013), 628–47. For the political obstacles to such initiatives in Ireland: Art Cosgrove, 'Ireland', in Christopher Allmand (ed.), *The new Cambridge medieval history: vol. VII, c.1415–c.1500* (Cambridge, 1998), 496–513: 510.

[360] On, e.g., the punitive effects of the system of 'coign and livery': Art Cosgrove, 'The Gaelic resurgence and the Geraldine supremacy: *c.* 1400–1534', in T.W. Moody and F.X. Martin (eds), *The course of Irish History* (Cork, 2011, new edition), 136–150: 137–8. Conducting overseas trade and diplomacy also faced considerable challenges: Brendan Smith, *Crisis and survival in late medieval Ireland: the English of Louth and their neighbours, 1330–1450* (Cambridge, 2013), 169.

nature of authority, and the fluctuating commitment of the English crown to its Irish Lordship. What is less widely recognised by historians is that Irish society's inclination towards violence in multiple forms and at a variety of scales was stoked, not just incidentally but repeatedly (Appendix 6), by hardship and scarcity. James Lydon plainly understood the connection. He considered the 1270–1 harvest crisis to be the catalyst that prompted the Irish of the Wicklow Mountains to raid the vacant archdiocese of Dublin's neighbouring lowland manors and thought it 'no coincidence that when [in 1294] Gaelic Leinster once more rose in rebellion, it was in the year of another great famine'.[361] Even in relatively law-abiding societies supply-side output failures of food and essential raw materials might prompt resort to crime (usually against property), protest, riot and violence.[362] When public authority failed and the moral economies of charitable giving and mutual social support broke down there was an even greater danger that those possessing the necessary armed might would take advantage of the situation and seek plunder, booty and ransom.

If dated volcanic eruptions are taken as a proxy for depressed growing conditions arising from sudden severe short-term climate forcing, the statistical analyses presented in Appendix 6 suggests that violence and war tended to follow in the train of bad weather and poor harvests and thereby greatly magnified the latters' social and economic consequences.[363] This locked society into a self-perpetuating cycle whereby weather-induced output shortfalls promoted lawlessness and lawlessness, in turn, eroded society's resilience to output shortfalls and thereby further endorsed the resort to violence at times of need. Eventually, by the fifteenth century, rustling and raiding had become almost a way of life in the thinly peopled livestock-farming regions of the Gaelic north and west.[364] By then patterns of atmospheric circulation had shifted with the result that years that were bad for England were no longer necessarily bad for Ireland and vice versa. This climatic divergence is manifest in the reduced and at times negligible or even negative correlation between the ring widths of Irish and southern-English oaks (Fig. 4). It was also the case that as the Irish agrarian economy became more pastoral, the hard winter weather that proved most challenging for Irish pastoral producers carried little penalty for English grain producers, who had most to fear from the wet spring and summer weather that was so favourable to grass growth.

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[361] Lydon, 'Land of war', 256–7, 260. Also, Simms, 'Political recovery of Gaelic Ireland', 275.

[362] Campbell, 'Nature as historical protagonist', 291–2, 296; Guido Alfani, Luca Mocarelli and Donatella Strangio, 'Italy', in Alfani and Ó Gráda, *Famine in European history*, 25–47: 42–3; for scarcity driven violence and rioting in fourteenth century Dublin: Finbarr Dwyer, *Witches, spies and Stockholm syndrome: life in medieval Ireland* (Dublin, 2013).

[363] Ludlow and Travis, 'STEAM approaches to climate change'.

[364] K.W. Nicholls, 'Gaelic society and economy in the high middle ages', in Cosgrove (ed.), *New history of Ireland, vol. 2*, 397–438: 413–15.

Nevertheless, the vital game-changing development, which in the mid-fourteenth century had sent Ireland's population plunging, with far-reaching consequences for the country's social, economic and political structures, was neither climate nor war *per se* but disease. It was the transformation of the epidemiological environment by the arrival of bubonic plague (*Yersinia pestis*) that gainsaid Gerald of Wales's earlier portrayal of Ireland as a healthy country and initiated a new demographic era dominated by high morbidity, high mortality and negative replacement rates.[365] The deaths of eminent individuals had always preoccupied Ireland's annalists and plague's deadly onset and frequent reappearances ensured that they had plenty to record, as the great and the good succumbed in sometimes dramatic numbers.[366] To add grist to their mill, social opportunism thrived on the sudden death from plague or other diseases of those holding important or administrative office and allowed 'new' families to rise to prominence, sometimes irrespective of their cultural origins.[367] In effect, such mortality crises might engender a 'state of exception', in which normal conventions and cultural norms were temporarily suspended, allowing room for potentially rapid social and political change.[368]

Plague's devastating impact upon population levels in Ireland, both immediately and in the long term, is also writ large in the changes to land use which then ensued. After 250–300 years when woodland had been in more-or-less

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[365] Between 1150 and 1249 annalistic references to extreme weather outnumber those to epidemic disease by approximately 7.5 to 1.0; by the less-healthy fifteenth century that ratio narrows to 2 to 1 (Fig. 2).

[366] For examnple, in 1489 the *Annals of the Four Masters* (also *of Ulster*) (https://celt.ucc.ie//published/T100005D/index.html (M1489.3-5)) reported: 'A great plague [raged] this year, of which great numbers died. It was so devastating that people did not bury the dead throughout Ireland. Redmond, the son of Owny, son of Farrell, son of Thomas, son of Mahon, son of Gilla-Isa Roe O'Reilly, died of it. Felim Oge, the son of Felim, son of Farrell, son of Thomas, son of Mahon, son of Gilla-Isa Roe O'Reilly; Donnell, the son of Torna O'Mulconry, intended Ollav of Sil-Murray; Donnell Cananach i.e the Canon, the son of Teige O'Birn; Cormac O'Conolly, head of the gallowglasses of O'Conor's rear guard; Ineen-duv, the daughter of O'Conor, i.e. Donough the black-eyed; Hugh Boy and Donnell Caech, two sons of O'Hanly; Rury Glas, the son of Rory, son of Mac Hugh; Mac Donough Reagh, i.e. Hugh; and Finola, the daughter of Mac Dermot Roe, all died of the plague'.

[367] A.S.K. Abraham, 'Upward mobility and seigneurial residences in late medieval Meath' in Arlene Crampsie and Francis Ludlow (eds), *Meath history and society: interdisciplinary essays on the history of an Irish county* (Dublin, 2015), 149–76. For upward mobility by families with Gaelic ancestry within the English Lordship: Sparky Booker, *Cultural exchange and identity in late medieval Ireland: the English and Irish of the four obedient shires* (Cambridge, 2018), 52–96.

[368] On the 'state of exception': Michael R. Dove, *Anthropology of climate change: an historical reader* (Chichester, 2014), 18. A concrete example is given by Jacqueline S. Solway, 'Drought as a revelatory crisis: an exploration of shifting entitlements and hierarchies in the Kalahari, Botswana', *Development and Change* 25 (1994), 471–95.

continuous retreat, the dendrochronological record implies that in the immediate aftermath of the Black Death oaks began to regenerate in increasing numbers, with regeneration accelerating following the fourth major plague outbreak in 1382–5 (Fig. 5). The upshot was that by the mid-fifteenth century Ireland was once again, albeit unevenly, a well-wooded country, with a rich store of timber upon which later builders would be able to draw (Fig. 5).[369] Without the negative and recurrent biological shock inflicted by plague, such a far-reaching landscape transformation (matched, moreover, by a corresponding re-advance of woodland across Europe) would be inexplicable.[370]

Plague, nevertheless, did not act independently of climate and herein, arguably, lies the most profound, if indirect, influence of the weather upon late-medieval Irish society. Plague's ancient reservoir regions in the semi-arid Asian interior were as much exposed to the changes in atmospheric circulation patterns set in motion from the late-thirteenth century as Ireland. The heightened ecological stress generated by abrupt swings from droughts to pluvials and then, suddenly, back to drought reactivated plague from its long dormant enzootic mode and propelled it on its westward migratory course.[371] By 1346, at the climax of a global climate anomaly, the disease had reached the Crimea and crossed over to become a deadly and fast-spreading human pandemic, reaching southern England and eastern Ireland almost simultaneously in 1348. Thereafter, with a ten to twelve-year lag, climatic conditions in newly-established plague reservoirs in inner Eurasia, especially the Caspian Basin, triggered successive reintroductions of the disease to Europe and eventually Ireland.[372]

At the same time, by means not yet fully understood, plague succeeded in maintaining itself within Europe, where it circulated between cities and especially ports and assumed the character of a recurrent background disease with frequent localised outbreaks of the sort reported in the Annals. Contemporaries had good reason to fear cool European summers and poor grain harvests as liable to provoke outbreaks of plague, whereas warm summers and abundant harvests diminished that risk (Appendix 7).[373] Often Ireland was on the receiving end of plague outbreaks that had originated elsewhere, triggered by weather effects and harvest shortfalls that had occurred beyond its shores. The deadly plague outbreak that ravaged Dublin and its hinterland in 1439 is a case in point. In England and Europe this

[369] Baillie, *New light*, 15–25; Nicholls, 'Woodland cover', 202–3.
[370] Campbell, *Great Transition*, 312–13; Kaplan, Krumhardt and Zimmermann, 'Prehistoric and preindustrial deforestation', 3023; Ljungqvist, 'Linking European building activity with plague history'.
[371] Campbell, *Great Transition*, 227–30; Kausrud, 'Modeling the epidemiological history of plague in Central Asia'.
[372] Schmid, 'Climate-driven introduction of the Black Death'.
[373] Above, notes 235, 238–9.

erupted in the immediate aftermath of the dreadful weather and back-to-back harvest shortfall of 1437–8.[374] Yet whereas Ireland appears to have been spared that harvest catastrophe it did not escape the continent-wide plague epidemic that followed in its wake and which likely levied a heavy toll on the country's already much diminished population.[375]

Plague in late-medieval Ireland, like famine, is more easily described than quantified. More can certainly be learnt about both from a closer critical engagement with the Annals and other sources, especially those emanating from the English administration in Ireland. Placing that record in the context of the more detailed and quantifiable evidence for England and other adjacent parts of Europe is also revealing. Bioarchaeology, as the excavated graveyards of Ballyhanna and Ardreigh have demonstrated, can also shed unique light on the health, nourishment and life expectancy of the majority of ordinary Irish people in whose fortunes and fates the annalists took such little individual interest.[376] Dendrochronology, too, can provide a chronological framework for contextualising these categories of information. Ireland's oak chronology spans a temporal range at a resolution and standard of chronological accuracy unmatched by any extant historical sources, even the island's remarkable Annals. Pollen preserved in peat bogs, sediments deposited in freshwater lakes, and speleothems formed in the country's many limestone caves are further natural archives from which palaeoclimatic information can potentially be extracted. It is therefore to be anticipated that future research will greatly add to the range of evidence currently available.

This essay therefore offers no more than a first pass at what combining this wealth of evidence from historical and natural archives can eventually reveal about the interactions between climate, disease and society throughout half a millennium when the global patterns of atmospheric circulation that determined Ireland's climate changed profoundly. It reveals an economically under-developed and mostly materially poor society, deficient in food security and, in its Gaelic regions, employing farming methods that exposed it cruelly to weather extremes. Scarcity and famine consequently remained periodically inescapable facts of life, to which violence of one form or another was a normative response. Across these five centuries, breaking this socially corrosive and economically destructive pattern of cause and effect was never long achieved. Nevertheless, it was plague, like violence often an indirect outcome of the weather, which from 1348 had the more decisive and enduring impact.

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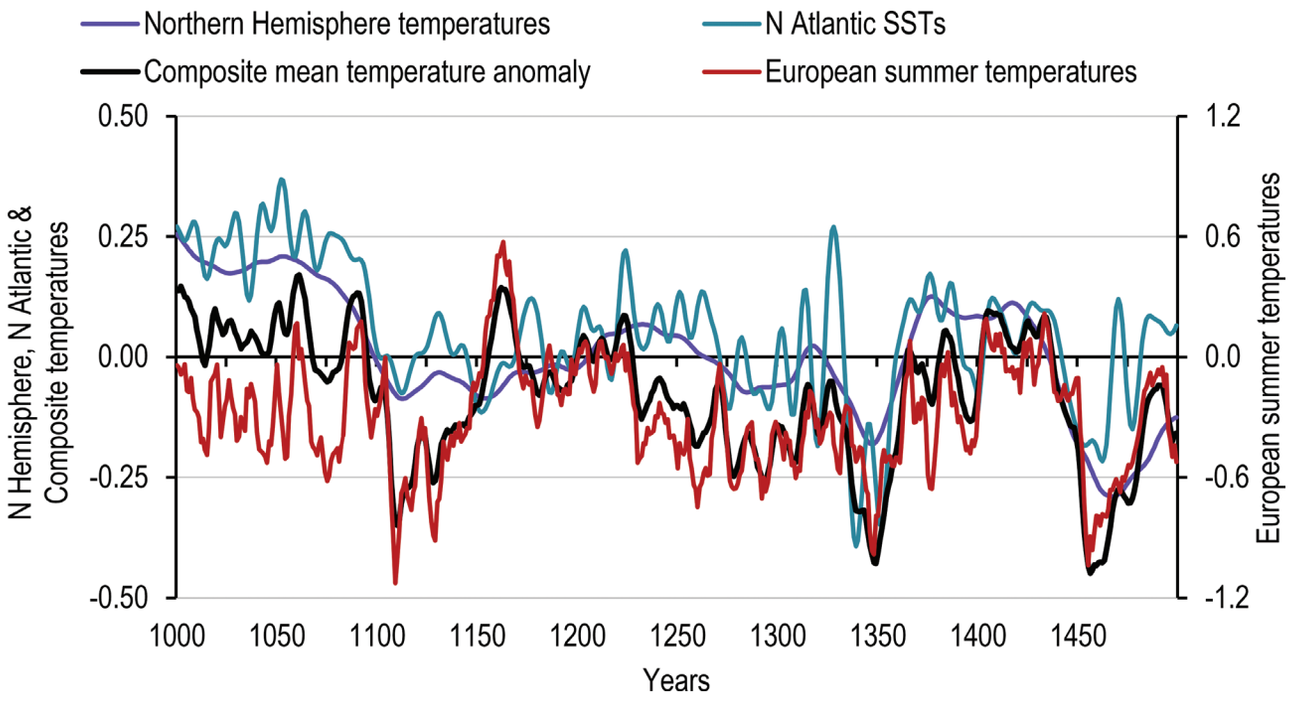
[374] Campbell, 'Grain yields on English demesnes', 153–4; Campbell and Ó Gráda, 'Harvest shortfalls', 870–3; Alfani and Ó Gráda, 'Famines in Europe', 8–9. As well as Ireland, plague was reported in Italy, Iberia, France, the Low Countries, Germany and Austria and Scandinavia: Biraben, *Les hommes et la peste*, vol. 1, 363–74.

[375] *Annals of the Four Masters,* 1439 (https://celt.ucc.ie//published/T100005D/index.html (M1439.16).

[376] McKenzie and Murphy, *Life and death in medieval Gaelic Ireland*, 388.

For all these reasons it is time that historians of late-medieval Ireland begin to take the weather seriously. The climate may scarcely have impinged overtly upon affairs of state and only exceptionally, as in the case of Edward Bruce, unambiguously compromised the grand schemes of ambitious men, but its effects upon the lives and livelihoods of ordinary people and the types and levels of adversity with which they had to contend were profound.

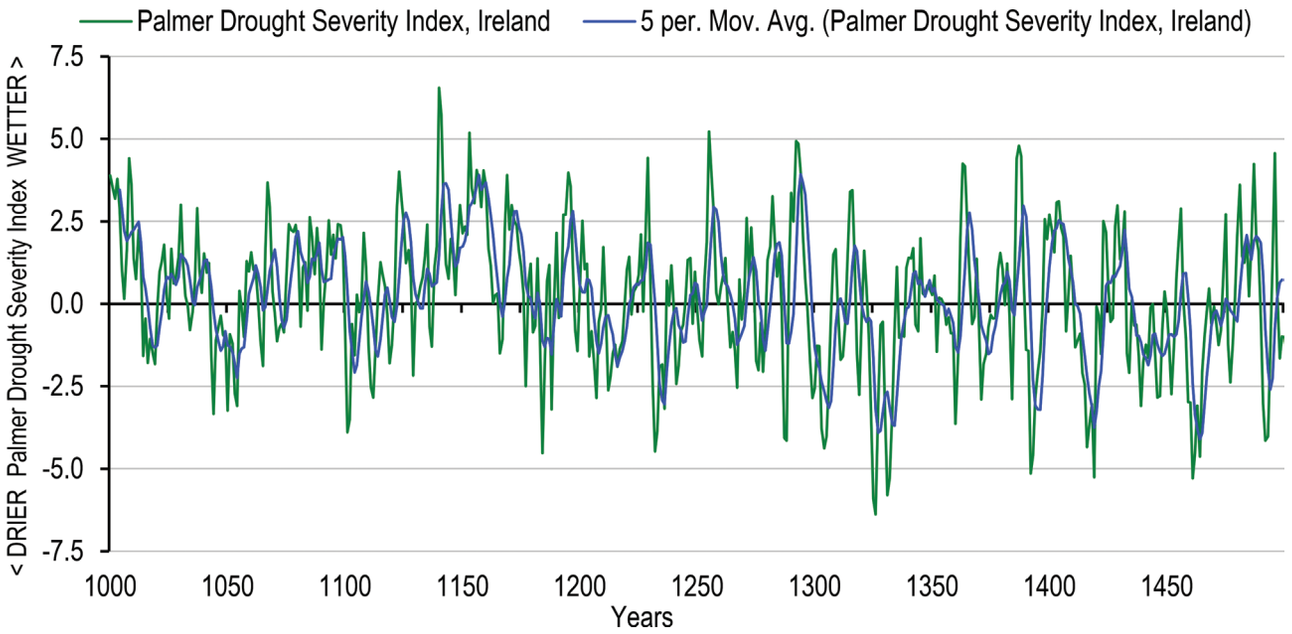
Appendices



Appendix 1—Northern hemisphere temperatures, North Atlantic sea-surface temperatures, European summer temperatures (5 year moving average) and a composite mean temperature series (11 year moving average).

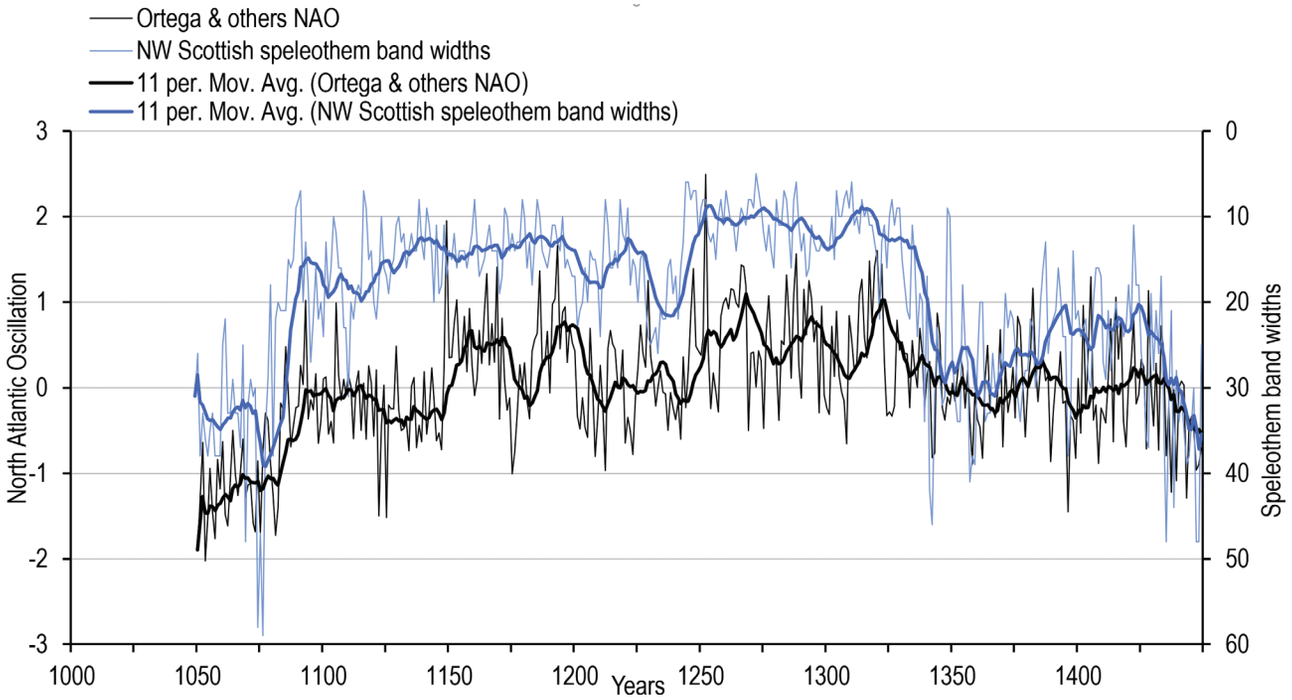
Sources: M.E. Mann *et al.*, 'Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia', *Proceedings of the National Academy of Sciences* 105:36 (2008), 13252–57. Data: www.ncdc.noaa.gov/paleo/metadata/noaa-recon-6252.html.

J. Luterbacher *et al.*, 'European summer temperatures since Roman times', *Environmental Research Letters* 11:2 (2016), L024001. Data: www.ncdc.noaa.gov/paleo/study/19600. Accessed 19/08/2016.



Appendix 2—Growing-season (i.e., spring–summer) soil moisture in Ireland according to the Old World Drought Atlas (OWDA).

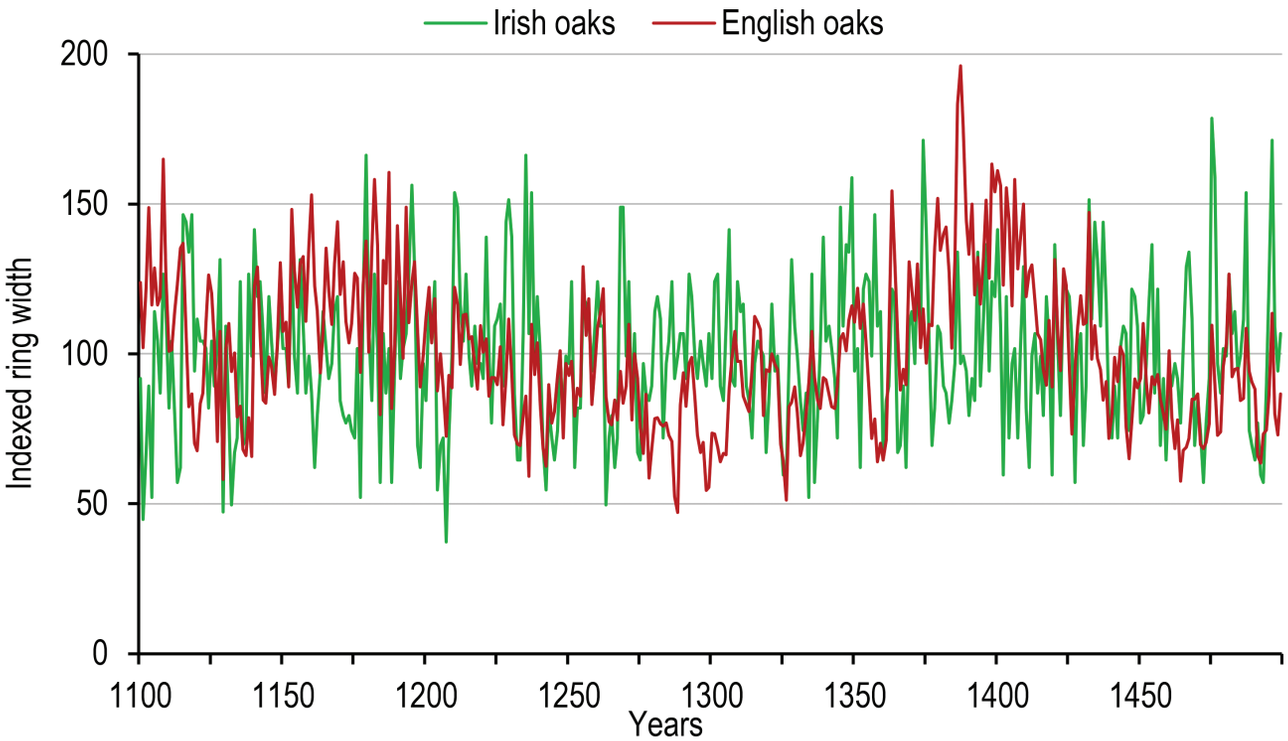
Source: Data from E.R. Cook *et al.*, 'Old World megadroughts and pluvials during the Common Era', *Science Advances* 1:10 (2015), e1500561. doi: 10.1126/sciadv.1500561.



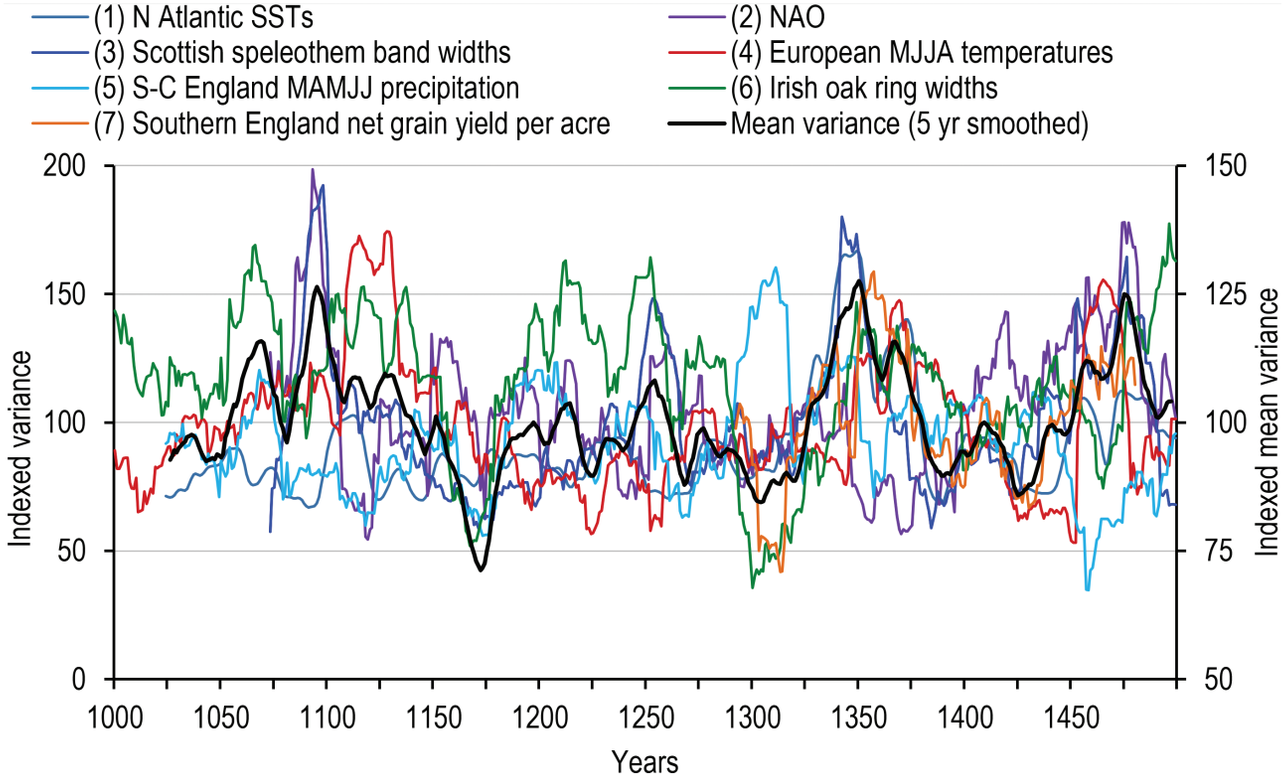
Appendix 3—Scottish speleothem band widths and the North Atlantic Oscillation (NAO).

Sources: Pablo Ortega *et al*., 'A model-tested North Atlantic Oscillation reconstruction for the past millennium', *Nature* 523:7558 (2015), 71–4. Data: www.ncdc.noaa.gov/paleo/study/18935.

C.J. Proctor, A. Baker and W.L. Barnes, 'A three thousand year record of North Atlantic climate', *Climate Dynamics* 19:5–6 (2002), 449–54. Data: www.ncdc.noaa.gov/paleo/study/5418.



APPENDIX 4—Ring widths of Irish oaks and southern English oaks.
Source: Data supplied by M.G.L. Baillie and David Brown.



Appendix 5—Index of Environmental Instability.

Note: the variance of each dataset has been standardised.

Sources:

(1) M.E. Mann *et al*., 'Proxy-based reconstructions of hemispheric and global surface temperature variations over the past two millennia', *Proceedings of the National Academy of Sciences* 105:36 (2008), 13252–57. Data: www.ncdc.noaa.gov/paleo/metadata/noaa-recon-6252.html.

(2) Pablo Ortega *et al*., 'A model-tested North Atlantic Oscillation reconstruction for the past millennium', *Nature* 523:7558 (2015), 71–4. Data: www.ncdc.noaa.gov/paleo/study/18935.

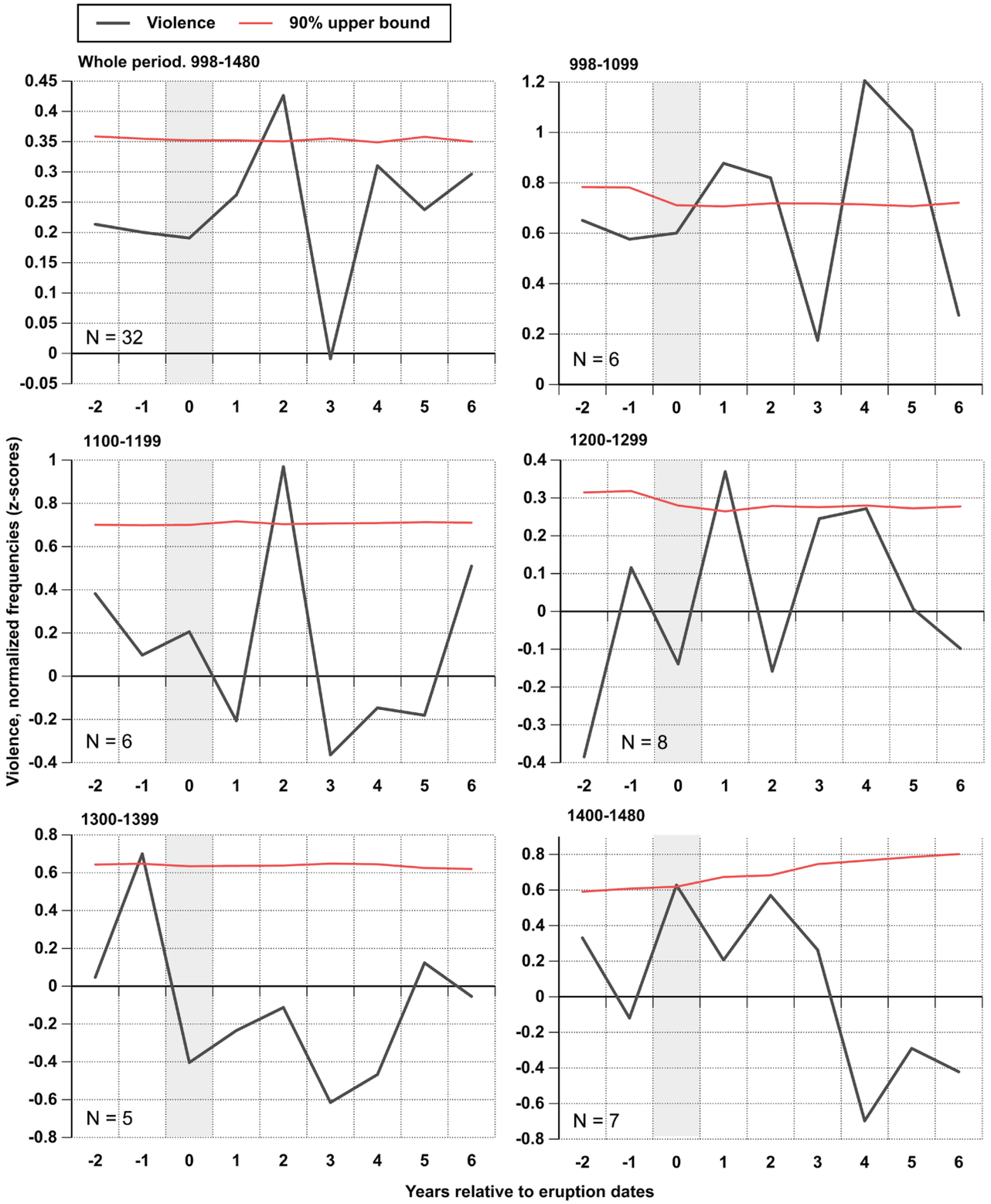
(3) C.J. Proctor, A. Baker and W.L. Barnes, 'A three thousand year record of North Atlantic Climate', *Climate Dynamics* 19:5–6 (2002), 449–54. Data: www.ncdc.noaa.gov/paleo/study/5418.

(4) J. Luterbacher *et al*., 'European summer temperatures since Roman times', *Environmental Research Letters*, 11:2 (2016), L024001. Data: www.ncdc.noaa.gov/paleo/study/19600. Accessed 19/08/2016.

(5) R. Wilson *et al*., 'A millennial long March–July precipitation reconstruction for southern-central England'. *Climate Dynamics*, 40:3–4 (2012), 997–1017. www.ncdc.noaa.gov/paleo/study/12907. Accessed 19/08/2016.

(6) Irish mean master oak-ring chronology supplied by M.G.L. Baillie (2003).

(7) B.M.S. Campbell and Cormac Ó Gráda, 'Harvest shortfalls, grain prices, and famines in pre-industrial England', *Journal of Economic History* 71:4 (2011), 859–86.


Violence
90% upper bound
Whole period. 998-1480
N = 32
998-1099
N = 6
1100-1199
N = 6
1200-1299
N = 8
1300-1399
N = 5
1400-1480
N = 7
Violence, normalized frequencies (z-scores)
Years relative to eruption dates

(Continued)

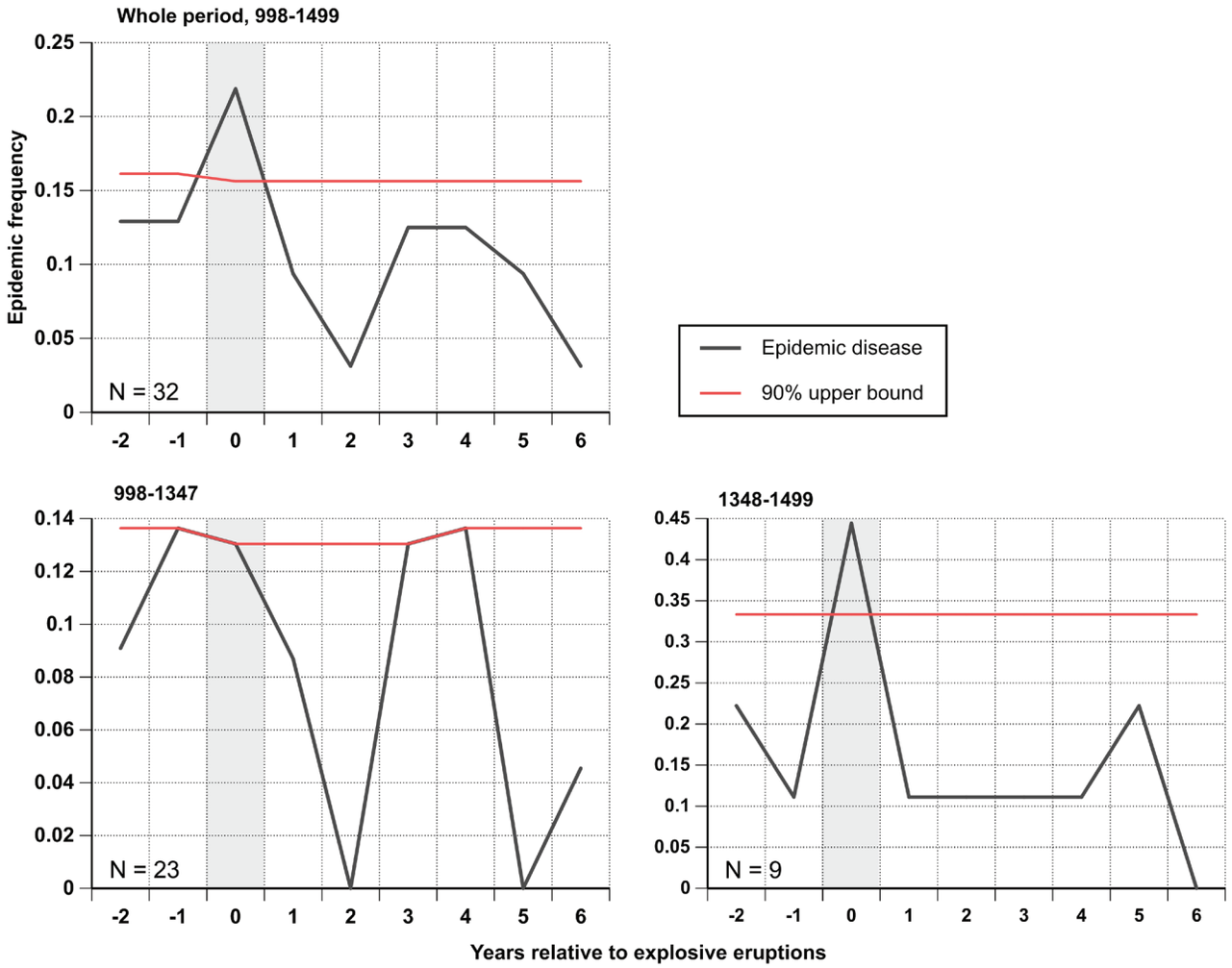
Appendix 6—Superposed epoch analyses (SEA) of a broad spectrum of violence reported in the *Annals of Ulster*, 998–1499 CE, relative to a polar ice-core-based reconstruction of volcanic climate forcing.

Notes and sources: Violence included in the analyses range from individual murders and homicides to mass killings and large-scale armed attacks on properties and territories reported in the *Annals of Ulster*. Each year's value is normalised according to the mean and standard deviation of itself and the previous 49 years, in order to ensure statistical comparability in the response to volcanic eruptions throughout the period under consideration.

The analysis focuses upon 32 major explosive eruptions with a VSSI of at least 1.0 Tg (an estimate of volcanic sulphate injected into the stratosphere, reflecting climate-forcing potential, and thus excluding 19 eruptions discernable in the ice-cores but of minimal climatic-forcing potential and consequently likely to introduce noise into the SEA analyses). Most eruption dates are estimated based upon counts of ice core layers, calibrated against tree rings and other independently dated records. They are therefore liable to a small chronological error of at most +/-2 years: Matthew Toohey and Michael Sigl, 'Volcanic stratospheric sulfur injections and aerosol optical depth from 500 BCE to 1900 CE', *Earth System Science Data* 9:2 (2017), 809–31: 812, 822 (original dataset made personally available to Francis Ludlow).

A whole-period analysis is presented first (top-left panel), compositing violence (black line) relative to all 32 volcanic events using a ten-year window, running two years before the estimated eruption dates (Years -2 to -1 on the horizontal axis), the estimated dates of the eruptions (Year 0) and the first six years following (Years 1 to 6). The red line depicts the 90 per cent upper bound of a randomly generated reference distribution (based upon 10,000 sets of random, Monte Carlo-style, draws from the whole-period violence dataset). Thus, any observed value that reaches or exceeds this bound (i.e., in which the black line meets or rises above the red line) can be deemed to have a 10 per cent or less chance of occurring purely by chance, if there were no underlying association between volcanism and violence. This exercise reveals a notable peak in average violence in Year 2. The specific probability of observing such a high value in Year 2 by chance alone is just 5.0 per cent (i.e., $p = 0.05$).

The next five panels examine the response in successive centuries, starting with the eleventh century. This confirms that in most centuries elevated levels of violence occurred in the first and/or second year following eruptions. This exercise complements the testimony of the texts themselves, which are only occasionally explicit respecting possible links between climatic stress and violence, but also cautions against assuming a simple mechanistic relationship between eruptions, weather effects and societal responses, in which violence can be expected to spike systematically in a particular post-eruption year. The uniqueness of each eruption event in location, magnitude, character, seasonality and background climatic context, as well as some small dating uncertainty, is likely the origin of much variation in the observed response, as indeed is the changing societal context in which each eruption occurred (with potentially varying levels of societal resilience and stability in the different periods).



Appendix 7—Superposed epoch analyses (SEA) of outbreaks of epidemic disease reported in the *Annals of Ulster*, 998–1499 CE, relative to a polar ice-core-based reconstruction of volcanic climate forcing.

Notes and sources: Epidemic disease as reported in the *Annals of Ulster*. In order to ensure comparability in the response to volcanic eruptions throughout the period under consideration, each year's epidemic disease count (in binary presence-absence (0,1) format) is normalised according to the mean and standard deviation of itself and the previous 49 years. The analysis is based on the same 32 major explosive eruptions with an estimated VSSI of at least 1.0 Tg as described in Appendix 6.

The results of this analysis suggest a genuine (if obviously indirect) association between explosive volcanism and epidemic disease outbreaks, which is conspicuously stronger for the bubonic plague era 1348–1499 than the pre-plague era 998–1347. Thus, in the plague era, 44.4 per cent of volcanic events (N = 9) coincide with reported epidemic outbreaks in the same year. The probability of such a high value occurring randomly in this year is just 6 per cent (see the note to Appendix 6 for details on the specific statistical testing underlying this probability estimate). Unsurprisingly, the result for the pre-1347 period is less clear, but still suggestive of an association between volcanically induced climatic disturbances and reported epidemics.