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Tree-ring growth shows that the significant population decline in Norway began decades before the Black Death

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ABSTRACT

The Black Death (1349–1350 in Norway) is often cited as the cause of a severe population decline and building hiatus in the middle of the 14th century. This paper analyses this hypothesis by matching the Black Death with human and environmental impacts on tree-ring growth. The number of buildings dated by dendrochronology in Norway shows a dramatic decline several decades before the plague. In Norway, the building hiatus, which has parallels in several other places in Europe, dates from the late-13th century almost to the 16th century. The first dated houses built after the plague date from the 15th century and many of the logs have exceptionally wide tree rings compared to timber from other periods. Assuming the rapid growth was because of an open landscape, the trees are likely to have grown on infields of farms abandoned due to the 14th century population decline. Since many of these fast-growing trees germinated in the early-14th century and the number of dated buildings drops dramatically several decades before the plague, the Black Death can hardly be the only reason for the population decline in Norway and one plausible explanation is that some environmental impact occurred decades earlier. The dendroclimatological evidence of cold and wet summers in the years before the plague is suggestive, but historical sources also pinpoint famine due to crop failure. They also tell of farms being abandoned several decades before the plague and mention periods of heavy rainfall and famine in the early-14th century.

1. Introduction

Reduced availability of timber felled during the 14th century has been experienced in several places when constructing tree-ring chronologies (Bartholin and Landstrøm, 1983; Baillie, 1995; Thun, 2009). This has been explained by a pause in the erection of new buildings associated with a population decline following outbreaks of the plague known as the Black Death (Berg, 1997: 95). The Black Death (1349–1350 in Norway) was the first in a series of outbreaks of an epidemic disease that had widespread consequences for politics, culture, economy and demography. Based on more than 100 studies of the Black Death, Benedictow (2004) estimated that as much as 60% of the population in Norway died due to the plague between the spring of 1349 and the winter of 1350, and that it caused a dramatic population decline in Asia and Europe in the mid-14th century.

Many Norwegian historians have argued that the Black Death in 1349–1350 was the sole cause of the population decline and the abandonment of farms in the late Middle Ages (Hasund, 1919; Lunden, 2002; Moseng, 2006). However, Dybdahl (2010, 2012) argued that climate was an important factor explaining the increased mortality. Plagues were common during the Middle Ages, and the added effect of climatic deterioration may explain why the consequences of specifically the Black Death became so severe. He also directed attention to the abandoned farms mentioned in *Diplomatarium Norvegicum* (DN), a collection of Norwegian letters and documents that are central for studies of the medieval period. One letter from 1340 tells of a private person leasing a farm outside Bergen (Fig. 1) that had been abandoned 10 years earlier. The letter also mentions several farms in Trøndelag (the region surrounding Trondheim) being abandoned in 1334, 1338 and 1342, showing that crises were emerging decades before the plague in 1349–1350 (Dybdahl, 2010: 206).

Eckstein (2007) gave examples of how dendrochronological data can be used to investigate past human behaviour and showed that human impact on tree-ring growth can provide knowledge about the timing of events and living conditions. In many countries, den-

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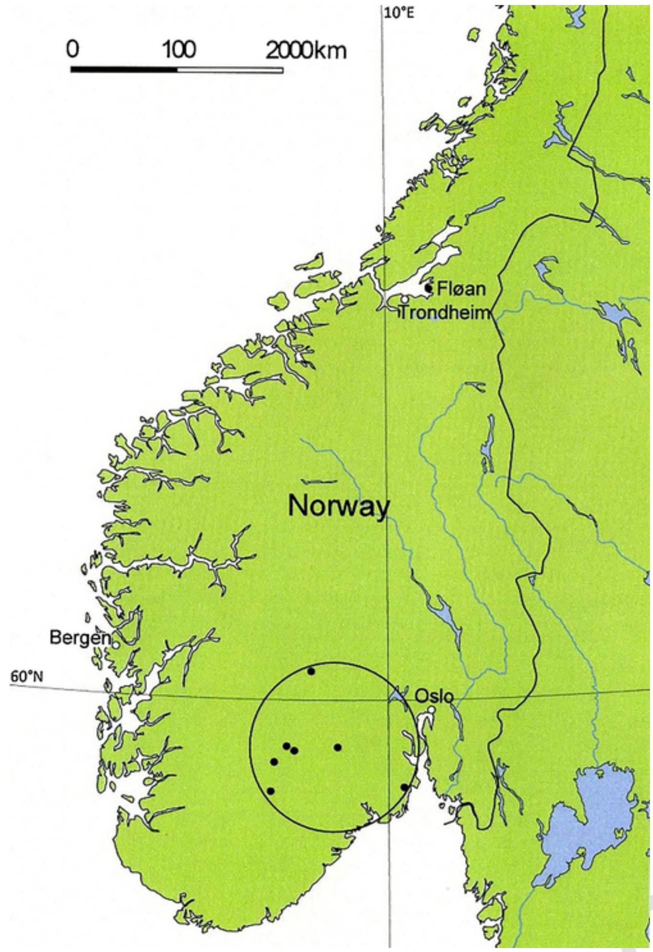

Fig. 1. Map showing the location of Trondheim, Bergen, Oslo and the eight 15th century timber buildings dated by dendrochronology in southern Norway as dots.

drochronologically dated buildings go more than a millennium back in time. In Norway, this has also enabled studies of variations in building techniques after the building hiatus in the 14th century, notably corner-timbering (Berg, 1989: 36–40; Thun, 2002; Stornes and Thun, 2012: 144) and splash whittling (Berg, 1989: 21–24; Thun, 2002: 257; Thun and Storsletten, 2011). The long pause likely meant that knowledge and traditional building techniques failed to be handed down from one generation to the next, and new techniques more easily gained a foothold when work recommenced.

Many decades of dendrochronological studies in Norway and more than 1000 dated buildings indicate that the building hiatus began before the plague in 1349–1350. There also seems to be a difference in the type of forests used for timber in the early-15th century compared to other centuries. Dendrochronological samples cored from logs of Scots pine (*Pinus sylvestris* L.), hereafter referred to as pine, felled in the beginning of the 15th century show surprisingly broad tree rings, indicating that these trees grew in an environment different from that of other periods. This unusually fast-growing timber coincide in time with the building hiatus and historical descriptions of population decline. This makes it reasonable to presume that these trees grew on abandoned farmsteads. A more detailed study of the dendrochronological material from this period should therefore provide valuable information on events in the decades before the Black Death.

More specifically, the aims of this paper are:

- To estimate when the trees began to grow on infields so that farm abandonment in the 14th century in Norway can be more precisely dated.
- To refine understanding of the length and date of the Norwegian building hiatus in the 14th century.
- To investigate whether environmental conditions can explain the dramatic consequences of the plagues in the second half of the 14th century.

2.Data and Methods

The material in Norway dated with dendrochronology to the 15th century comes from three different sources. Logs from eight standing buildings (Fig. 1) in southern Norway (75 samples), samples from wooden objects excavated at the Archbishop's Palace in Trondheim (62 samples) and archaeological material from Oslo (79 samples).

To investigate differences between the material from the 15th century and other periods, the average tree-ring widths and the number of tree-rings in the 75 samples from building timber dated to the 15th century (eight houses) are compared with samples taken from building timber dated before 1350 (200 logs) and logs felled between 1500 and 1750 (170 logs). This provides an estimate of the growth increase on abandoned infields compared to the natural growth in a forest. All the samples originate from buildings in different parts of southern Norway and are described by Thun (2002, 2005).

The archaeological material is very heterogeneous and originates from a variety of artefacts. Several samples from the 15th century excavated in Trondheim are from wells and 58 samples from Oslo derive from cog boxes (i.e. corner-connected logs filled with stones and used to stabilise waterfronts, described by Stornes and Thun (2012)). Some of these artefacts are made from exceptionally fast-growing trees, and several samples contain fewer than 50 tree rings. Tree-ring widths in archaeological material may therefore not be suitable for comparison with logs used in timber houses prior to 1300 and after 1500, because the selection of fast-growing, slender trees might have been deliberate. The variation in tree-ring widths from different periods is therefore best suited in building timber only.

Dybdahl (2010: 206) mentioned farms abandoned decades before the Black Death in 1349–1350. Tree rings could provide more information because the germination and growth of the trees on abandoned fields can be dated. These trees provided mature timber for buildings when the infields were cleared and building started again in the early-15th century. Their felling would also have cleared such fields for renewed arable farming (Fig. 2). Dendrochronology can provide the latest possible year for germination of trees that grew on the infields of abandoned farmsteads.

The core samples were taken at the lowest possible point on the logs to provide a maximum number of tree rings. However, even if the pith is present, the dating of the innermost tree ring will never be anything other than a *terminus ante quem,* the latest possible date for the germination of the tree. In such fast-growing trees, there is probably a very low number of tree rings down to the germination year. Very little material from northern Norway, here defined as the area north of Trondheimfjord (Fig. 1), has been dated to the medieval period (Thun and Storsletten, 2011). Material from northern Norway is therefore not included in this study.

To investigate the climatic conditions in the late-13th and early-14th centuries, the results presented here are compared with written reports of crop failure and famine, records of volcanic forcing and reconstructed summer temperatures from several places in Europe.

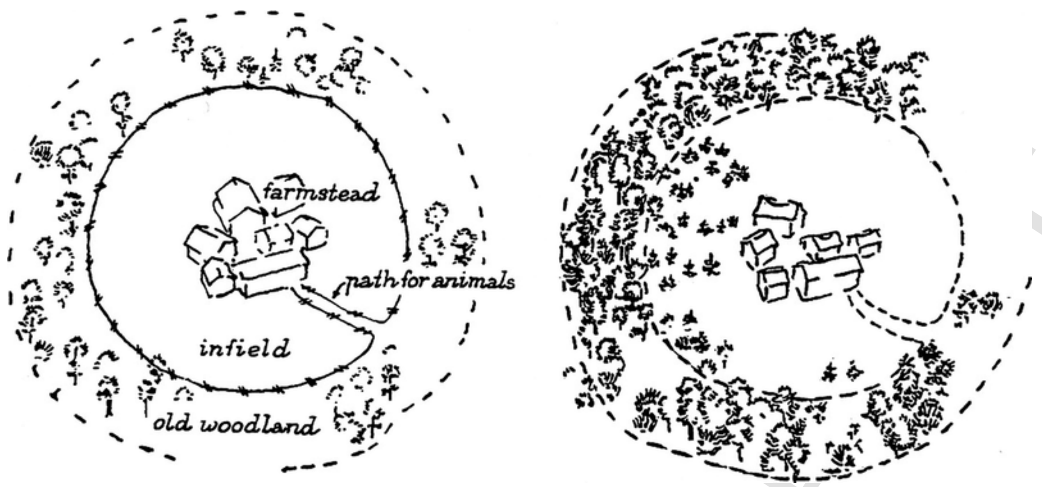

Fig. 2. Schematic illustration of the overgrowing of a farmstead infield. Inhabited farm on left, abandoned farm on right. Drawn by Arne Berg in 2002.

3. Results

3.1. The length of the building hiatus

More than 1000 buildings have so far been dated with dendrochronology in Norway and several hundred are from before 1300 and after 1500. In contrast, only four standing buildings date from the last decades before the Black Death, between 1300 and 1350, have been dated with dendrochronology (Table 1), and building activity declined already during the second half of the 13th century. These four buildings consist of excellent material and one of them is a stave church (Reinli Stave Church). No buildings in southern Norway are dated to the second half of the 14th century and only eight to the 15th century (Table 2). A histogram along a timescale shows the number of buildings dated as of 1998 as a decadal distribution (Fig. 3). A decrease in building activity is visible in the late-13th century. Since 1998, no

Table 1
Norwegian buildings dated to the 14th century. The germination year is a *terminus ante quem* because it is not known from where on the tree the samples were taken.

Name	Type of building	Average tree-ring number	Latest germination	Felled
Stave	Storehouse	179	1144	1323–1324
Reinli	Stave church	198	1127	1325–1326
Søre Lande	Storehouse	92	1244	1336–1337
Austad	Storehouse	114	1230	1344–1345

Table 2
Norwegian buildings dated to the 15th century. The germination year is a *terminus ante quem* because it is not known from where on the tree the samples were taken.

Name	Type of building	Average tree-ring number	Latest germination	Felled
Fløan	Chapel	81	1313	After 1394
Seljord	Church	81	1321	1402–1403
Heierstad	Storehouse	48	1358	1406–1407
Nordre Sandnes	Storehouse	156	1273	1429–1430
Sitje Søndre	Storehouse	147	1324	1471–1472
Klaureid	Storehouse	111	1371	1482–1483
Sudigard Bøen	Storehouse	155	1335	1490–1491
Su Seljord	Storehouse	142	1351	1493–1494

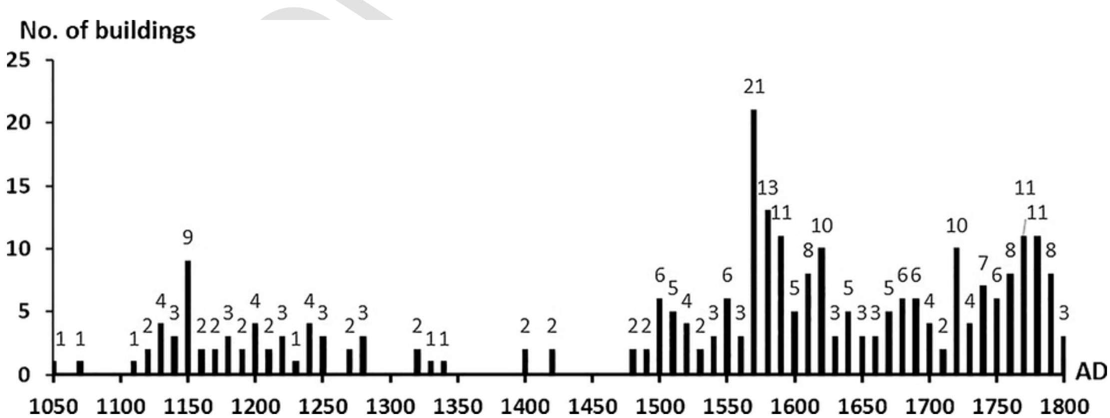

Fig. 3. Decadal variation of dated buildings from southern Norway as of 1998. The Fløan Chapel, dated after 1394, is not included as the exact felling year is unknown. Since this count, there have been no additions to the 14th or 15th centuries but several hundred have been added before 1300 and after 1500.

buildings have been found to date from the 14th or 15th centuries, but several hundred buildings have been added before 1300 and after 1500.

The excavated archaeological material from Trondheim shows the same result (Fig. 4). A decadal frequency distribution of felled logs shows a decrease in building activity already from the second half of the 13th century, and it resumes as late as the 15th century. The youngest dendrochronologically dated sample from the Archbishop's Palace (Norwegian: Erkebispegården) in Trondheim before the building hiatus is from 1281, and the next dated sample was felled in 1427, almost 150 years later (Fig. 4). The Archbishop's Palace is the only part of the city where building recommenced so soon after the hiatus. This was emphasised by Sandnes (1977: 121), who pointed out that the Archbishop in Nidaros (an ancient name for Trondheim) was one of the few who was capable of initiating extensive building work so soon after the recession.

Thus, the building hiatus dates from the late-13th to the early- to mid-15th century. In the early-16th century and onwards there is a great increase in building activity and several hundred buildings date from the 17th century, probably reflecting a population increase. Fewer wooden artefacts are available for dating from the younger period, mainly due to decay in the upper levels of excavated profiles.

Samples taken from building material in southern Norway show an average tree-ring width of 0.89 mm and the average number of tree rings of 160 for the period before 1350 AD. For the period from 1500 until 1750 the average tree-ring width is 0.82 mm and the average number of tree rings is 180 (Table 3). Many trees selected for building material during the 15th century, however, grew in a different kind of forest. They derive from trees that grew rapidly and were mature for building timber at a much lower age compared to other periods (Fig. 5). For timber taken from houses dated with dendrochronology to the first half of the 15th century, the average tree-ring width is 1.67 mm and the average number of tree rings is only 90. For the second half of the 15th century, the average tree-ring widths in analysed building timber is 1.22 mm and the average number of tree rings is 140 (Table 3). This rapid growth starts before the Black Death plague in the middle of the 14th century and correlates in time with the building hiatus.

3.2. Dating farm abandonment by the overgrowing of infields

Dybdahl (2010, 2012) mentioned abandoned farms recorded in historical sources. Trees must have overgrown infields on abandoned farmsteads, which gave a basis for rapid growth. When building recommenced in the early-15th century, the trees had already reached suitable dimensions for building timber. They grew near the farmstead and their felling cleared infields for new agricultural activities (Fig. 2), (see also Baillie, 1995: 124–126). Dendrochronological analysis can date the innermost tree ring, thus giving an estimate, a *terminus ante quem*, for the germination year, and consequently an estimate of when the farmsteads were abandoned (Tables 1 and 2).

3.3. Buildings

The majority of the logs from the eight 15th-century buildings came from trees that germinated before the Black Death (Fig. 6).

3.4. Archbishop's Palace

Approximately 20% of the samples from the Archbishop's Palace in Trondheim were taken from trees whose innermost tree ring dates from 1350 or earlier, thus dating the overgrowing of abandoned infields to the period between the early-14th century and approximately the 1430 s (Fig. 7). This reveals that building activity recommenced in the 15th century and the infields were cleared of mature timber, freeing space for cultivation or grazing. The material from the Archbishop's Palace consists of logs of approximately the same dimension, but the number of tree rings varies.

3.5. Archaeological material from Oslo

Many trees started to grow early in the 14th century. None of the fast-growing trees started to grow later than the early-15th century (Fig. 8), indicating that the abandoned farms were cleared for new agricultural activity at that time.

4. Discussion

As infields were cleared in the early-1400s, the surrounding woodland, (Fig. 2) with more suppressed and slower growth, could gradually become an alternative supplier of timber. This can be demonstrated by comparing the growth of the samples from the first half and the second half of the 15th century (Table 3). The good quality of the timber in the four buildings from the first half of the 14th century (Table 1) also indicates that shortage of trees for timber is not a likely cause of the building hiatus. In Norway, dating of the 14th century building hiatus and of what is presumed to have been the abandonment of farmsteads in the same period shows that both these events started several decades before the Black Death. This is in agreement with Dybdahl's (2010:206) review of historical sources and contradicts the notion that the Black Death was the sole cause of the population decline in the late Middle Ages.

4.1. Similar results from other countries

The consequences of the Black Death were widespread and it is natural to compare the results outlined here with some other countries. Work in south-east Sweden in the early-1980s showed that the houses

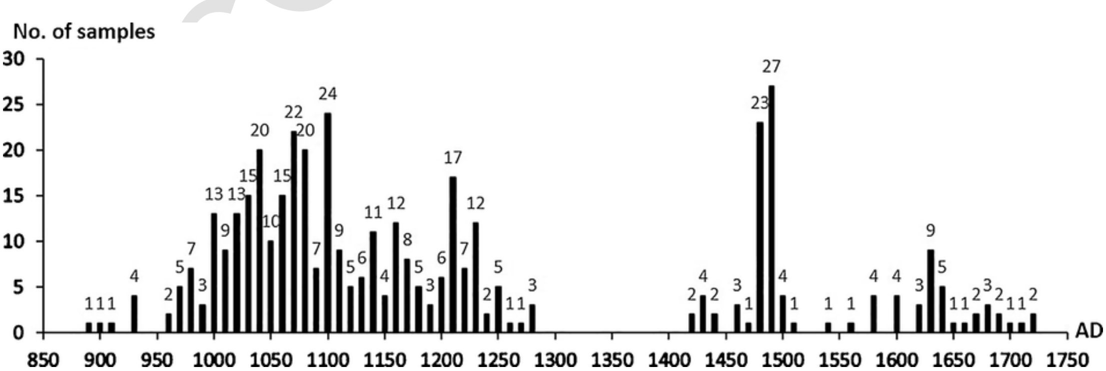

Fig. 4. Decadal frequency distribution of the felling dates of logs from archaeological excavations in Trondheim.

Table 3
Average tree-ring widths and tree-ring numbers of dated buildings.

Periods	Before 1350	1400–1450	1451–1499	1500–1750
Average tree-ring widths	0.89 mm	1.67 mm	1.22 mm	0.82 mm
Average tree-ring numbers	160	90	140	180

from the 15th century contained timber that had grown rapidly, leading to the assumption that these trees had germinated on infields that were abandoned as a result of the Black Death (Bartholin and Landstrøm, 1983). Bartholin (pers. comm.) compiled data on the number of tree rings in samples from before 1350 and from timber used in buildings from the mid-15th century onwards. This revealed that the early medieval timber had a larger number of tree rings than trees felled between 1470 and 1500. In England, more than four thousand villages that were settled during the Medieval Warm Period, described as the "lost villages of England", had to be abandoned after 1300 (Behringer, 2010:101) and in Germany and northern France, Büntgen et al. (2011) attributed disruption of building activity to the Great Famine and the Black Death.

(1982: 214, 1995: 26–27) presented the 14th century gap in several oak chronologies from the British Isles and mentioned that the same problem also occurs in northern Germany (Bailie 1995: 27). Baillie (2006: 23) also referred to work by Ernst Hollstein and Peter Kuniholm

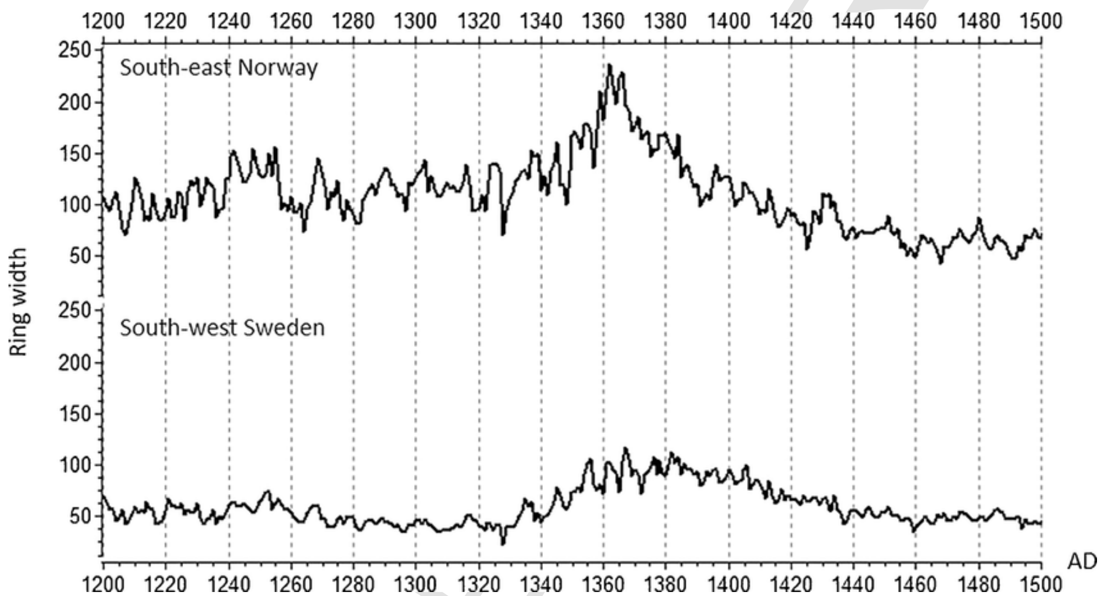

Fig. 5. Regional curves, also including timber felled after 1500. The tree-ring patterns for south-west Sweden (lower curve) and south-east Norway (upper curve) show a decline in the tree-ring width after 1258 and a very narrow tree ring in 1328. The tree-ring pattern also shows increased tree-ring widths in the second half of the 14th century. The Swedish chronology was provided by Thomas Seip Bartholin.

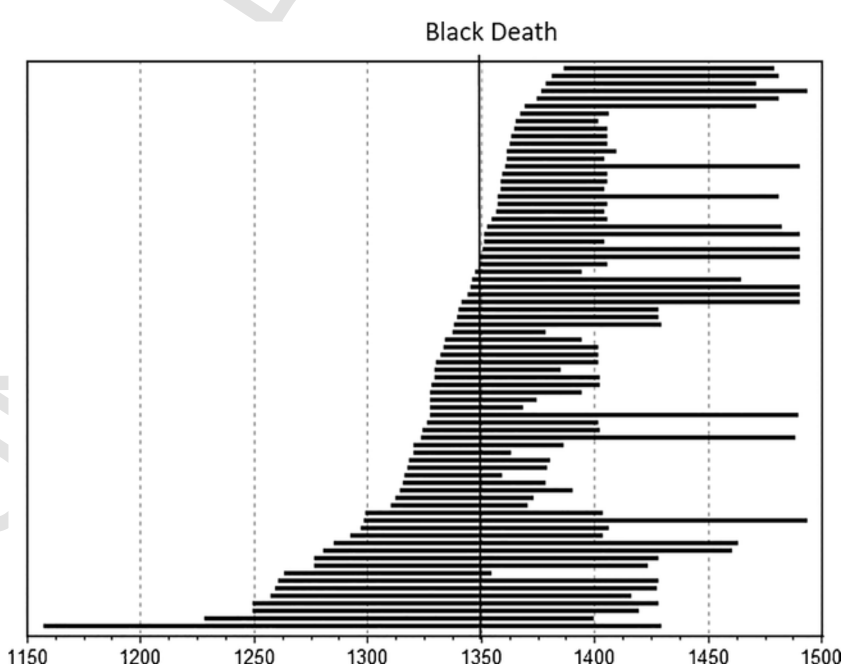

Fig. 6. Bar diagram showing the dated logs in the 15th century houses.

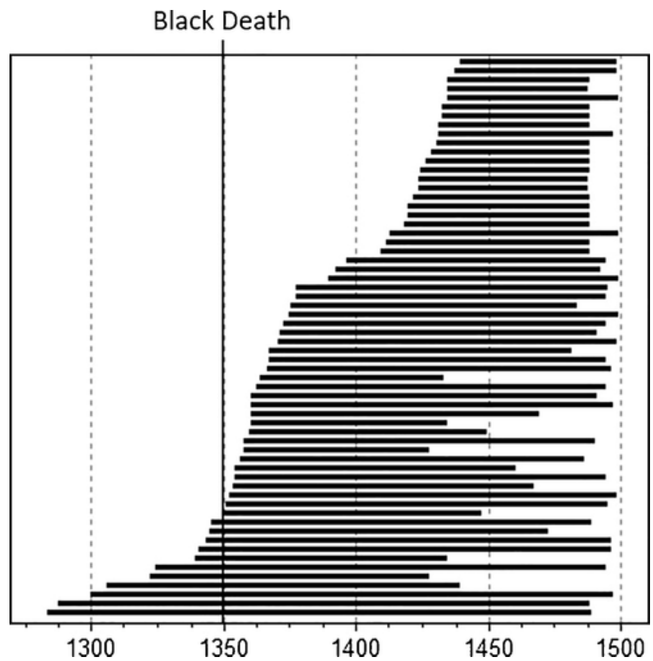

Fig. 7. Bar diagram showing the 62 dated logs from the 15th century at the Archbishop's Palace in Trondheim.

Fig. 8. Bar diagram showing the 79 dated logs from archaeological material from Oslo.

that shows a building hiatus in Germany and the Aegean for almost 100 years from the first decade of the 14th century. The building hiatus and the overgrowing of abandoned infields are thus widespread in Europe.

4.2. Tree-ring results compared to historical sources

Lucas (1930) attributed the European famine of 1315, 1316 and 1317 to heavy rain and flooding which destroyed the crops. Historical sources describe demographic crises that, in time, are in perfect accordance with the building hiatus shown by tree rings. In Norway, many late medieval farms were growing grain at its altitudinal and latitudinal limits. Disastrous climatic events would have had a great impact on crop failure, brought famine and probably led to numerous farms being abandoned from the early-14th century onwards. Tree germination on infields in the early-14th century matches in time the great European famine of 1315-17, which is often referred to as the most famous catastrophe in late-medieval European history.

A volcanic eruption in the tropics in this period was described as the "largest volcanic eruption of the past millennium" (Stothers, 2000). Lavigne et al. (2013) believed that it occurred at the Samalas volcano, adjacent to Mount Rinjani on Lombok Island in Indonesia, and took place in AD 1257 or 1258. Tree-ring widths in Norwegian and Swedish pine chronologies (Fig. 5) declined for approximately a decade from 1258. The volcanic eruption of 1257/58 had widespread consequences. Dybdahl (2016: 36) mentioned reduced solar irradiance, famine, increased mortality and disease. Stothers (2000: 365) also described heavy summer and autumn rain in 1257 and 1258, which ruined crops in several parts of Europe; "…famine in the countryside that drove thousands of villagers into London, where many of them perished from hunger".

Baillie (2006:135) identified several periods with narrow tree rings in the decades before 1349, especially 1292–1295 when "Something unpleasant took place …", A "downfall" is also significant during the early-1290s in the Scandinavian pine chronologies, the narrowest tree ring being in 1296 (Fig. 5). A very narrow tree ring in 1328 is also present in Norwegian and Swedish pine chronologies, but it is less significant in pine chronologies in the northern part of Scandinavia. This indicates a cold summer that year, at least in continental parts of southern Norway and Sweden and corresponds to a volcanic forcing event noted by Gao et al. (2008).

4.2.1. Climate in the 13th and 14th centuries

The results presented in this paper point to a demographic crisis in Norway that started several decades before the onset of the Black Death. As this matches historical sources reporting famine, disease and crop failure in the late-13th and early-14th centuries, it begs the question of why, if not only because of the plague, the population declined. Although other societal disruption causes, i.e. non-environmental factors such as economic recession, cannot be ruled out, one plausible reason is climatic deterioration. Disastrous climatic events such as volcanic eruptions and heavy rainfall can have a great effect on crop failure, especially on farms growing grain at its altitudinal and latitudinal limits, which was the case for many late medieval farms in Norway. If plagues hit a population already weakened by food shortage, the declining state of health might have led to dramatic consequences during the outbreaks in the second half of the 14th century.

Baillie (1982: 214) referred to Hatcher (1977) and pointed out that the plague hit a population in England with economic problems and "exhaustion of recently cleared marginal land". The Black Death hit many European countries and the Middle East (Benedictov, 2004). If a demographic crisis predates and caused the Black Death it had to be very widespread, which again raises the question of a global environmental event. Baillie (1995) studied tree-ring chronologies from various parts of Europe and the USA, and found several periods back in time with global reductions in tree-ring growth. For the 14th century, Baillie (2006: 31) presented the average tree-ring widths in 13 oak chronologies across northern Europe. These showed a decline during the 1290s, 1320s and 1330s. Baillie (2006: 32) also provided information on a reduction of the North Atlantic sea-surface temperature in the same periods based on studies of deuterium. High deuterium depletion in ice cores from Greenland in the same periods shows that the reduction in tree-ring widths in oak coincides with a temperature decline in Europe. This was even more noticeable when Baillie (2002: 75, 2006: 37) presented chronologies from 5-pointed smooth growth indices constructed from various global chronologies, all showing periods with declining tree-ring growth in 1292–1295 and the 1330s and 1340s.

The IPCC (2013) depicts European JJA temperatures in the late-13th and early-14th centuries as being only slightly below the 1881–1980 average, and uncertainties in this period are largely due to a decreasing number of independent proxies with a strong climatic signal back in time. In central Europe, Büntgen et al. (2011) proposed that unfavourable climate, i.e. a first cold spell around 1300 and wetter summers during the 13th and 14th centuries, debilitated the underlying health conditions that contributed to the crisis following the Black Death. Reconstructed April-September temperatures from the Central Scandinavian Mountains in Sweden show a cold spell around 1275 when temperatures approached the well-documented cold period around 1600 (Zhang et al., 2015) and another June-August temperature reconstruction from the same area indicates two periods of anomalous cold temperatures between 1256 and 1350 (Fuentes et al., 2017). These events coincide with an early Wolf minimum, which is a period of low solar activity between 1280 and 1350 (Stuiver and Quay, 1980), but it is not uniformly reproduced in other European reconstructions (e.g. Büntgen et al., 2006; Esper et al., 2014; Rydval et al., 2017). Although the circumstantial evidence is present, it is therefore difficult to conclude whether low summer temperatures were a major cause for the crop failures in the period preceding the Black Death. No reconstruction of summer precipitation is available for the medieval period in Norway. However, a reconstruction of June daytime relative humidity for south-west Sweden shows sustained summer wetness during the Medieval Climate Anomaly (*sensu lato*; 1050-1350) and short periods of persistently moist summers in the last half of the 13th century and the first half of the 14th century. The latter of these seems to correspond to the rainy summers of 1315-1317 described by Lucas (1930). Pluvial pulses were also found to dominate the warm season in the 13th and 14th centuries in Germany (Büntgen et al., 2010).

5. Conclusions

The onset of the building hiatus normally associated with the Black Death is dated to the late-13th and early-14th centuries in Norway, thus preceding the plague by several decades. The hiatus lasted until the early- to mid-15th century and is paralleled by similar breaks in building in several other parts of Europe.

The buildings erected in the 15th century in southern Norway are made from logs that reached a mature size at a young age, corresponding to trees growing in an open landscape. It is reasonable to believe that the timber was taken from infields when building resumed after the hiatus and that these trees grew on previously abandoned farmsteads.

Dating of the 15th century buildings indicates that overgrowing of abandoned infields, like the onset of the building hiatus, started decades before the Black Death. This matches contemporary reports of crop failure and famine, and shows that the Black Death probably hit a population that was already in decline. Reconstructions of warm season temperature and precipitation for the 13th and 14th centuries indicate that increased rainfall and cold spells might have dominated the climate in Europe prior to the plague, but there is variation between different records and regions. A climate-related cause for the population decline is therefore plausible, but more studies of temporal and spatial climatic variability in this period are needed to offer a conclusion.

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