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The AD 536/540 climate event in Sweden – a review

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The middle of the first millennium AD in Sweden witnessed significant changes in the archaeological record, prompting various discussions about the underlying causes. This paper reviews the research developments surrounding the global climate cooling, which was caused by severe volcanic eruptions in AD 536/540 and is referred to as the Late Antique Little Ice Age or Fimbulwinter, and its potential impacts, with a specific focus on Swedish Iron Age societies, drawing upon published climatic and archaeological data. Furthermore, it discusses the research gaps that impede a comprehensive understanding of the potential relationship between the AD 536/540 event and socioeconomic changes in Iron Age Sweden. Additionally, it suggests that isotopic analysis will offer additional insights and help bridge the research gap.

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As a result of growing concerns about the impacts of contemporary climate change, research in recent years has shown an interest in exploring the relationship between climatic fluctuations and human responses in the past (Diaz & Trouet 2014; Rick & Sandweiss 2020). The various challenges, spanning from climate change, food insecurity, and animal extinction to ecological disaster and societal instability, that our planet is facing, have led researchers from different disciplines to investigate past human responses to climate change in order to find ways to mitigate the impact of contemporary climate change (Redman 2005; Diaz & Trouet 2014; Rick & Sandweiss 2020). In archaeological research it has become a major subject, even though it presents great challenges (Rick & Sandweiss 2020). According to Kintigh *et al*. (2014), understanding past human societal responses and the reasons behind their vulnerability or resilience to climatic fluctuations is one of 25 great challenges in archaeological research. Human societies are complex systems, and they can react to environmental and climatic changes in various ways (Diaz & Trouet 2014), thus it would be presumptuous to think that we could find one general response to climate change no matter what the society looks like or where it is situated.

Abrupt climatic alterations have been considered as one of the main driving factors behind societal reorganization, civilization collapses, population declines and material culture changes around the world (Weiss *et al*. 1993; Gill 2000; Haug *et al*. 2003; Drake 2012, 2017; Ganiev 2014; Büntgen *et al*. 2016; Douglas *et al*. 2016; Psomiadis *et al*. 2018; Degroot *et al*. 2022). Large explosive volcanic eruptions can, for example, cause significant climate impact because of their substantial SO_2 emissions and the subsequent formation of sulfphate aerosols in the stratosphere. These aerosols reflect incoming solar radiation, reducing the amount of sunlight available for primary production at the Earth's surface (Kostick & Ludlow 2015). A long-lasting cold event caused by multiple severe volcanic eruptions in AD 536/540 has been recorded in various historical sources and dendrochronological and ice-core data (Stothers & Rampino 1983; Stothers 1984; Rampino *et al*. 1988; Baillie 1994, 2008; D'Arrigo *et al*. 2001; Arjava 2005; Larsen *et al*. 2008; Ferris *et al*. 2011; Churakova *et al*. 2014; Sigl *et al*. 2015; Toohey *et al*. 2016; Dull *et al*. 2019; Helama *et al*. 2019). This event was first recognized by Stothers & Rampino (1983), and the extent of its global impact has been confirmed by high-resolution climatic data (Baillie 1994, 2008; Larsen *et al*. 2008; Churakova *et al*. 2014; Sigl *et al*. 2015; Büntgen *et al*. 2016; Toohey *et al*. 2016; Dull *et al*. 2019; Helama *et al*. 2019). Several studies have considered the AD 536/540 event as one of the factors contributing to sociopolitical changes such as settlement abandonments, population declines, migrations, the spread of the Justinian plague, the transformation of the Roman Empire, the invasion of Italy by the Lombards, the rise of the Ottoman Empire as well as the Arabic Empire, the collapse of the dynasties in China and the crisis (Hiatus) in the Mayan society (Stothers 1999; Gill 2000; Gunn 2000; Hirschfeld 2006; Ganiev 2014; Kostick & Ludlow 2015; Büntgen *et al*. 2016; Newfield 2016; Fuks *et al*. 2017; Helama *et al*. 2018; Fell *et al*. 2020). The event has also been connected to severe famine and economic crisis around the world owing to crop failure (Stothers & Rampino 1983; Stothers 1999; Arjava 2005; Woods 2010; McCormick *et al*. 2012; Kostick & Ludlow 2015; Breeze 2016; Fuks *et al*. 2017; Helama *et al*. 2018). Less is known about the impact of this event on Scandinavian societies (van Dijk *et al*. 2022).

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In Scandinavia, the consideration of climate change as a driving factor for the observed changes in the archaeological record in the middle of the first millennium AD began in the 1950s and 1960s (Arrhenius 1955; Almgren 1957; Königsson 1968; see Gundersen 2019 for research development in Norwegian archaeology). Gräslund (2007) revived the discussion of climate change, and specifically the AD 536/540 event, as one of the causes behind the 6th century crisis and developed the so-called Fimbulwinter theory, which influenced several subsequent studies (Gräslund & Price 2012; Löwenborg 2012; Arrhenius 2013; Bondeson & Bondesson 2014; Tvauri 2014; Price & Gräslund 2015; Zachrisson 2017; Gundersen 2019, 2021; Solheim & Iversen 2019). The AD 536/540 event in Scandinavian research has been linked to the increased number of gold hoard depositions, different ritual practices, settlement and burial abandonments, demographic decline, famine and the spread of ergotism and Justinian plague (Axboe 1999, 2001; Gräslund 2007; Gräslund & Price 2012; Löwenborg 2012; Arrhenius 2013; Bondeson & Bondesson 2014; Tvauri 2014; Price & Gräslund 2015; Solheim & Iversen 2019).

This paper will review the research developments of the AD 536/540 event and its possible impacts with a focus on Swedish Iron Age societies, using published climatic and archaeological data. The aim of this paper was to review (i) the research history of the AD 536/540 event, (ii) the palaeoenvironmental changes in Sweden during the Late Holocene and (iii) the changes in the Swedish archaeological record during the middle of the first millennium AD, and to discuss (iv) what is missing from the research in order to understand a possible relationship between the AD 536/540 event and socio-economic changes in Iron Age Sweden.

Background

The AD 536/540 event

In the early 1980s, when Stothers & Rampino (1983) searched for evidence of historical volcanic eruptions in written sources from the Mediterranean, they uncovered the AD 536 event. They were able to establish chronological correlations between the historical sources describing the event and available climatic data (Stothers & Rampino 1983). Following this, Arjava (2005) compiled all available historical sources from the Mediterranean region to investigate the effects of this event, including descriptions from Cassiodorus, who described the Italian famine in AD 537. Other historical sources, e.g. from Europe (Britain, Ireland), the Middle East, and Asia (China, Korea, Japan), also refer to this event as a period marked by summer frosts, severe famine, and population decline (Rampino *et al.* 1988; Baillie 1991, 1994; Woods 2010; Newfield 2018).

In early research, this event was described as atmospheric veiling and cooling resulting from the emission of sulphuric acid aerosols into the atmosphere, coming from a tropical volcanic eruption in Rabaul on the island of New Britain, Papua New Guinea (Stothers & Rampino 1983; Stothers 1984; Rampino *et al.* 1988). Sulphate aerosols from volcanic eruptions can affect radiation, atmospheric and surface temperatures, and local weather conditions, leading to worldwide climate cooling (Churakova *et al.* 2014). Baillie (1994) questioned the volcanic origin of the AD 536 event owing to the limited ice-core evidence for volcanic activity, and instead he suggested that this event could be associated with a comet or an asteroid, which was later supported by Rigby *et al.* (2004). However, this assumption was withdrawn some years later (Baillie 2008), after new evidence of large eruptions, when Larsen *et al.* (2008) provided data from sulphate deposits in ice cores supporting the volcanic origin of this event. Dendrochronological data further pointed out two volcanic eruptions, one in AD 536 and one in AD 540 (Baillie 1994, 2008). This was confirmed by Sigl *et al.* (2015) using ice-core data, where they found evidence of at least two large volcanic eruptions that had occurred, one in AD 536 and one in AD 539 or 540. While the origin of the first eruption in AD 536 was proposed to be in the Northern Hemisphere (Larsen *et al.* 2008), Ferris *et al.* (2011) rather considered a large eruption in the tropics as its origin. The source of the AD 539/540 eruption has been suggested to be the Tierra Blanca Joven eruption of Ilopango, a volcano in El Salvador (Dull *et al.* 2019).

The prolonged cold conditions that followed the two eruptions had a larger effect in the regions in the Northern Hemisphere than in the Southern Hemisphere (Sigl *et al.* 2015; Büntgen *et al.* 2020, 2022). Dendrochronological data indicated that the effect had a wide geographical distribution from Mongolia and Siberia (D'Arrigo *et al.* 2001; Churakova *et al.* 2014) to Europe (Baillie 1994; Büntgen *et al.* 2016; Helama *et al.* 2019) and North America (Salzer & Hughes 2007). The period from AD 536 to 545 was the coldest decade of the past two millennia, with the year AD 536 being extremely cold (Larsen *et al.* 2008; Sigl *et al.* 2015; Büntgen *et al.* 2020). Summer temperature reconstructions showed a temperature decrease of 1.6–2.5 °C in AD 536 and one of 1.4–2.7 °C in AD 541 in Europe (Sigl *et al.* 2015). Toohey *et al.* (2016) reconstructed monthly mean temperature anomalies and found a decadal temperature decline of 0.7 °C for AD 536–545, with a mean temperature decrease of 2.0 °C after the AD 540 volcanic eruption. Summer temperature reconstructions from Scandinavia and Finland showed decreased temperatures of around 1.5–2.0 °C in AD 536 and 540 (Briffa *et al.* 1990, 1992; Esper *et al.* 2012). Büntgen *et al.* (2016) suggested that three large volcanic eruptions in AD 536, 540, and 547 resulted in a long-lasting cooling from AD 536 to 660, which is referred to as the Late Antique Little Ice Age (LALIA) (Büntgen *et al.* 2016, 2020). The duration of the LALIA has been doubted as the evidence for a prolonged

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cold period lasting until AD 660 is not found widely across the Northern Hemisphere, and also owing to the fact that the LALIA overlaps with a previously determined cold period, the Dark Ages Cold Period (Helama *et al.* 2017a,b). In response to this, Büntgen *et al.* (2017) doubted the term Dark Ages Cold Period, as they claimed that this term is limited by its unknown origin and length. Furthermore, van Dijk *et al.* (2022) suggested that the cooling lasted for approximately 20 years after the eruptions, and in their model, it is not possible to identify a century-long cooling. According to Büntgen *et al.* (2016) and Helama *et al.* (2018), the cold conditions were sustained by ocean and sea-ice feedbacks, and reduced solar radiation.

The AD 536/540 event had more profound effects than other, more recent and well-known volcanic eruptions such as the Tambora eruption in AD 1815, which caused worldwide crop failure and famine (Baillie 1994). The AD 536/540 event has been considered as one of the factors, together with political and economic conditions, that contributed to the societal changes recorded in this period worldwide (Stothers 1999; Gill 2000; Gunn 2000; Hirschfeld 2006; Ganiev 2014; Kostick & Ludlow 2015; Büntgen *et al.* 2016, 2022; Newfield 2016; Toohey *et al.* 2016; Drake 2017; Fuks *et al.* 2017; Helama *et al.* 2018; Fell *et al.* 2020). The possible effects of this event could be crop failures and famine, and it has been suggested that it contributed to the spread of Justinian plague and population decline (Stothers & Rampino 1983; Baillie 1991, 1994; Stothers 1999; Arjava 2005; Stathakopoulos 2007; Woods 2010; Gräslund & Price 2012; McCormick *et al.* 2012; Kostick & Ludlow 2015; Breeze 2016; Büntgen *et al.* 2016; Newfield 2016; Fuks *et al.* 2017; Helama *et al.* 2018; Fell *et al.* 2020). Helama *et al.* (2018) highlighted that not only the cold conditions but also the reduction in solar radiation could contribute to the outbreak of famine and plague as a result of malnutrition and deficiency of vitamin D. Temperature fluctuations would mainly have affected agricultural production in northern marginal and high-altitude regions, especially in Scandinavia and the Baltic countries (Rampino *et al.* 1988; Toohey *et al.* 2016). This spatial variability also agrees with the observation by Arjava (2005) about some written sources in the Mediterranean that did not refer to the climate event.

The AD 536/540 event in the Swedish research

Migration Period Crisis

The 5th and the 6th centuries AD are considered as a period of sociopolitical turmoil and economic crisis in Sweden and Scandinavia in general (Price & Gräslund 2015). The changes in the archaeological record have been termed the Migration Period Crisis in early research (Näsman & Lund 1988; Berglund 2003), and the reasons behind this crisis in the middle of the first millennium AD have been debated for a long time (Stenberger 1933, 1955; Pettersson 1955; Nerman 1963; Seger 1982; Widgren 1983; Ambrosiani 1984; Flink 1986; Herschend 1988, 2009; Fallgren 2006). Multiple theories such as war, migrations, societal changes, Justinian plague, climatic change, and soil deterioration have been suggested for causing the observed population decline, abandonment of settlements, and agricultural crisis in Sweden (Stenberger 1933, 1955; Pettersson 1955; Nerman 1963; Seger 1982; Widgren 1983; Flink 1986; Herschend 1988, 2009).

Stenberger (1933, 1955) suggested that war was the reason for the settlement abandonment on the islands of Öland and Gotland. His conclusion was based on his observation of the destruction of the houses by fire and the discontinuity in grave sequences, along with the high number of gold hoard depositions dated to this period (Stenberger 1955: p. 1164). A similar interpretation was given by Nerman (1923, 1963), who posited a crisis period at around AD 475–550 resulting from war and emigration. He suggested that a significant proportion of the population migrated from Gotland to the Baltic countries at around AD 500, leading to a period of great turmoil on the island (Nerman 1923: p. 6, 1963: p. 20; Stenberger 1955: p. 1165). Herschend (1988: p. 62, 2009) interpreted the changes as a result of the fall of the Roman Empire, and he claimed that there was an economic relationship between the Roman Empire and Scandinavia, which was disrupted owing to the empire's fall, leading to long-term social stagnation in Scandinavia (Herschend 2009). On the other hand, Gräslund (1973) viewed the Justinian plague of the 540s as a possible explanation for this crisis.

The first time that climate change was considered was by Olof Arrhenius (1955). He applied phosphate analysis at the Vallhagar site on Gotland and observed that most of the Iron Age settlements were situated on clay areas (Arrhenius 1955: p. 1062). He interpreted the discontinuity as a change in the way of living and cultivation methods, suggesting that increased precipitation during the latter part of the Migration Period had catastrophic consequences on agriculture in clay areas, resulting in starving cattle stocks (Arrhenius 1955: pp. 1062–1063). Conversely, Pettersson (1955: p. 56) concluded that soil degradation could be a more probable reason for the abandonments, as the wet conditions could be beneficial for the dry soils of Gotland. Almgren (1957) agreed that climate and other natural conditions contributed to the settlement abandonments. Königsson (1968) suggested that climate change was the main cause for changes in the settlements of Öland during the Migration Period. Soil deterioration resulting from climatically related leaching and deforestation has been proposed by Sjöbeck as a significant factor leading to settlement abandonment (Sjöbeck 1950; Stenberger 1955: p. 1177). Intensification of cultivation leading to soil exhaustion and changes

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in agricultural technological tools were considered as possible reasons for the observed changes in the archaeological record, but they were rejected by Widgren (1997: p. 50).

Carlsson (1977) expressed doubt regarding the abandonment of settlements and provided examples of settlement continuity on Gotland. Additionally, he rejected the idea of a crisis, asserting that only a small proportion of the settlements (around 10–15%) were abandoned, whereas the majority remained in use (Carlsson 1984, 1988: p. 38). He also argued that the reduction in settlements occurred from the 5th until the 17th century, highlighting that it was a long process (Carlsson 1988: p. 40). Early research doubted climate deterioration as an explanation for the changes in Sweden during the middle of the first millennium AD owing to limited evidence of major climatic disturbances (Stenberger 1955: p. 1177). Näsman (1988: p. 11) characterized some of the previously given interpretations as monocausal and insufficient, suggesting that multiple factors could have contributed to the changes during the Migration Period. He viewed the changes in the archaeological record as a gradual development rather than a rapid change (Näsman 1988: p. 12). It is interesting here to note the different connections to climate change and resilience in terms of the different soil types in different areas.

Fimbulwinter or Dust Veil Event

The first attempt to connect changes in the archaeological record to the AD 536/540 event was made by Axboe (1999, 2001), who explained the increased number of sacrificial gold deposits dated to the Migration Period as a desperate effort by humans to bring back the sun. However, the idea of Fimbulwinter or Dust Veil Event was developed by Gräslund (2007), and later in cooperation with Price (Gräslund & Price 2012; Price & Gräslund 2015). Gräslund (2007) argued that the AD 536/540 event was the inspiration for the Norse myths of Fimbulwinter and Ragnarok. Together with Price (Gräslund & Price 2012; Price & Gräslund 2015), he highlighted the significant impact of this event on Scandinavian societies, resulting in crop failures, settlement abandonments and depopulation. Price & Gräslund (2015) also suggested a link between the disappearance of the sun symbol from imagery at the end of 6th century and the AD 536/540 event. This research inspired other scholars in Scandinavia and the Baltic area (Löwenborg 2012; Arrhenius 2013; Bondeson & Bondesson 2014; Tvauri 2014; Zachrisson 2017; Solheim & Iversen 2019).

Arrhenius (2013) argued that changes in ritual practices at Helgö were linked to the impact of the AD 536/540 event, including the use of bread as burial gifts, indicating famine and the importance of bread at that time. She also suggested that the impact of this event caused the end of bronze casting at the site (Arrhenius 2013). Löwenborg (2012) suggested that the demographic changes that occurred in Sweden were caused by the AD 536/540 event, perceiving climate change as a tool used by the elite to take advantage of the land abandonments and to create social change. Löwenborg (2012) and Zachrisson (2017) claimed that this event played a catalytic role in changes to property rights. Tvauri (2014) investigated the impact of the event to societies in Estonia, Finland and Scandinavia, concluding that this crisis not only caused a severe famine but also led to societal and cultural changes. He also pointed out that the climatic impact did not severely affect the societies in Finland, where subsistence relied on hunting and fishing (Tvauri 2014), thus bringing up the topic of different modes of resilience in different areas depending on the prevailing economy.

The Fimbulwinter concept has been a debated issue in Swedish archaeology (Näsman 2012; Moreland 2018). Näsman (2012), in his commentary on Löwenborg's (2012) work, supported the idea that climate alone is insufficient to explain the changes in the archaeological record, characterizing this approach as monocausal and natural deterministic. Whereas he did not deny that this climate event could have contributed to demographic decline, he argued that other factors were also at play (Näsman 2012). He further contended that changes in the archaeological record started as early as the 3rd to 4th centuries, preceding the AD 536/540 event, and that some of these changes continued into the 7th to 8th centuries (Näsman 2012). Svedjemo (2014) also supported the causes behind the changes being multiple, including political, economic and social causes. Widgren (2012) sought to understand settlement abandonment by examining previous settlement expansion and the societal character before the 6th century. He perceived the crisis not only as a response to the climatic fluctuations but also as a response to multiple societal factors, especially considering the diverse responses in different areas of Sweden (Widgren 2012). Spatial and temporal variability is a key argument in critiquing the Fimbulwinter theory (Gundersen 2019). Another argument against a causal relationship between climate and socioeconomic changes is the connection between broadly dated changes in archaeological record with precisely dated climatic evidence and the fact that a lot of studies assumed this causal link without investigating the societal vulnerability to climate change (Widgren 2012; Moreland 2018). Nordvig & Riede (2018) critically discussed the issue of linking 13th century myths with archaeological data of the 6th century, concluding that it is not possible to determine if the myth is based on actual events or if it is a fictive narrative.

Recent research indicates the necessity for a new theoretical approach to gain a deeper insight into human vulnerability and responses to climate change (Gundersen 2019, 2021). This suggestion stems from the recognition that the absence of analytical frameworks can

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lead to misunderstandings regarding the relationship between concurrency and causation (Gundersen 2019, 2021; Gjerpe 2021). Gundersen (2019) emphasizes that the extent of vulnerability or resilience to climatic changes, coupled with the capacity for adaptation and the severity of the event, determines the impact on societies. He further suggested that rather than engaging in debates solely about the impact of the climate event, research should delve into how and why Iron Age societies were affected by this event, and what led different groups to exhibit varying levels of vulnerability and resilience to crisis (Gundersen 2019, 2021). Gundersen (2019, 2021) suggested a multicausal framework in which the environmental impact is recognized together with long-term societal trajectories as possible contributors to social, cultural, and economic change.

Possible impact of the AD 536/540 event on Swedish societies

Agriculture is heavily affected by various environmental factors such as temperature fluctuations, humidity, precipitation, solar radiation, and soil conditions. These elements directly impact crop growth, harvest quality and quantity, as well as the spread of epidemics, indirectly contributing to the potential emergence of famine (Xoplaki *et al.* 2001). Bondeson & Bondesson (2014) asserted that the climatic fluctuations during the 6th century in Scandinavia may have facilitated the expansion of fungi, resulting in crop failure, famine, and a decline in both human and animal populations. Ergot, caused by the fungus *Claviceps purpurea*, is parasitic to cereals and grasses and thrives under cold/wet conditions (Bondeson & Bondesson 2014). Ergot can result in food poisoning, affecting humans by causing low fertility, miscarriage, hallucinations and even death, and domestic animals by resulting in stagnation of their milk and eventual death (Bondeson & Bondesson 2014). Rye is highly susceptible to ergot, but barley, wheat, and many other plant species can also be affected by it (Bondeson & Bondesson 2014). An increased importance of rye during this period has been observed in Estonia and Sweden (Grabowski 2011; Tvauri 2014). Evidence of ergot has been discovered in Sorte Muld on Bornholm and at Vallhagar on Gotland dated to the Migration Period (Helbaek 1955: p. 693; Bondeson & Bondesson 2014). Even though there is evidence for the existence of the fungus in Iron Age Sweden, the proposed connection with the AD 536/540 event is still not certain (Gundersen 2021: p. 55).

A link between the AD 536/540 event and the Justinian plague has been suggested by several studies (Stothers 1999; Stathakopoulos 2007; Gräslund & Price 2012; Sigl *et al.* 2015; Büntgen *et al.* 2016; Newfield 2016; Helama *et al.* 2018; Fell *et al.* 2020). The Justinian plague, caused by the bacteria *Yersinia pestis*, was transferred to humans via rodents, and probably had numerous outbreaks from AD 541 to 750 in the area of Mediterranean and beyond (Wagner *et al.* 2014; Newfield 2016). The AD 536/540 event may have triggered a subsistence crisis, leading not only to malnutrition but also to migrations that facilitated the spread of the plague (Stathakopoulos 2007; Newfield 2016). While several studies have proposed that the Justinian plague reached Scandinavia (Gräslund 1973; Seger 1982; Flink 1986; Stathakopoulos 2007; Price & Gräslund 2015; Solheim & Iversen 2019), the only aDNA evidence confirming the existence of plague in Northern Europe comes from Germany (Wagner *et al.* 2014; Gutsmiedl-Schümann *et al.* 2018). Thus, the assumption of the Justinian plague's existence in Scandinavia is mainly based on evidence of settlement and burial abandonments during the middle of the first millennium AD (Gundersen 2021: p. 57). The possible consequences of the AD 536/540 event could have been enhanced by ergotism and plague. However, further research is needed to verify the extent and the impact of both ergotism and plague on Iron Age Sweden (Gundersen 2021: p. 60).

Data on climatic fluctuations and changes in the archaeological record in Sweden

Palaeoclimate data

The Late Holocene in Northern Europe is characterized by a trend towards colder and wetter conditions, which in some cases can be explained by forcing factors such as solar activity fluctuations and volcanic eruptions (Snowball *et al.* 2004; Wanner *et al.* 2008; Seppä *et al.* 2009; Wastegård 2022). There is evidence of a transition to wetter and colder conditions spanning from around 1750 to 1250 BC in numerous Swedish records (Snowball *et al.* 2004; Bergman 2005; Borgmark & Wastegård 2008; de Jong *et al.* 2009; Wastegård 2022). Aeolian deposits and peat records from SW and central Sweden indicate cold, wet and stormy winters in the years 2250 BC, 1350 BC, and 850–250 BC (Björck & Clemmensen 2004; de Jong *et al.* 2007; Rundgren 2008). This period was followed by warm/dry conditions at around 1050 BC and cold/wet conditions at around 850 BC (Berglund 2003; de Jong *et al.* 2007; Borgmark & Wastegård 2008; Wastegård 2022). Peat records from central and northern Sweden indicate wet conditions at 550–150 BC and AD 650 whereas the oxygen isotope data of diatom silica suggests cold summer temperatures at 50 BC (Rosqvist *et al.* 2004; Rundgren 2008). Raised humidity and declined summer temperatures have been recorded in the Scandian Mountains post-50 BC (Bergman 2005: p. 26).

More stable and dry climatic conditions occurred up to around AD 450. The following period was characterized by an abrupt shift to wetter and colder conditions, which has been recorded in the climate records in Sweden (Wastegård 2022). Records from peat bog cores and oxygen stable isotopes of lacustrine carbonates from south-western and south-central Sweden indicate cold and stormy winters at AD 250, 450, 500, 600, 850, and

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1550 (Björck & Clemmensen 2004; de Jong *et al*. 2007; Borgmark & Wastegård 2008; Andersson *et al*. 2010). However, tree-ring and peat stratigraphy data show cold and wet conditions in AD 200–400 and 750–900, as well as a dry period at AD 400–600 (Gunnarson *et al*. 2003; Linderholm & Gunnarson 2005). Changes in humidity levels have been recorded by analyses of Testate amoebae and aeolian sediment influx from a bog in south-western Sweden, indicating wet conditions from around AD 450–720 (de Jong *et al*. 2007, 2009). The peat stratigraphy data show a shift towards wet conditions in AD 650 and 750 in southern, central, and northern Sweden (Svensson 1988; Rundgren 2008). Oxygen isotopes in lake sediments show cold air masses during the summer period, which influenced the summer temperatures in north Sweden during AD 750 (Rosqvist *et al*. 2004).

In the Northern Hemisphere, cold climatic conditions prevailed during the mid-first millennium AD (Wastegård 2022). Studies have referred to a cold period from AD 400 to 765 as the Dark Ages Cold Period (Helama *et al*. 2017b). This cold period partially overlaps with the LALIA, spanning from AD 536 to 660 (Büntgen *et al*. 2016). Summer temperature reconstructions from northern Sweden show cool conditions at AD 500–700 and 790–870, with a 2 °C temperature drop in AD 536 (Briffa *et al*. 1990, 1992; Grudd *et al*. 2002; Esper *et al*. 2012). A recent study by Arthur *et al*. (2024), which utilized climate simulation and radiocarbon dating from four regions in Norway and Sweden, shows decreased temperatures and reduced precipitation following the AD 536/540 event. Specifically, while the overall regional temperature dropped by about 1 °C, inland areas experienced a more significant reduction, ranging from 1 to 1.5 °C, compared with coastal areas, which experienced a decrease of 0.25–0.5 °C (Arthur *et al*. 2024). This could indicate different responses to the climatic change in coastal and inland areas.

Wastegård (2022) posited that palaeoclimate data from Sweden align more closely with the Dark Ages Cold Period than the LALIA owing to the presence of cold/wet conditions both before and after the LALIA period. Wet shifts identified span from AD 250 to 650, revealing a complex pattern of climatic variability in Sweden (Wastegård 2022). Consequently, further research is needed to investigate climatic variability during the first millennium AD and evaluate the impact of AD 536/540 event on Iron Age societies in Sweden (Wastegård 2022), also taking into account regional differences.

Changes in the archaeological record

Crop and animal husbandry

Permanent fields were established in southern Sweden during the Late Bronze Age (Grabowski 2011, 2014: p. 13; Widgren & Pedersen 2011). Hulled barley (*Hordeum vulgare var vulgare*) was used as a primary crop, whereas bread/club wheat (*Triticum aestivum* spp. *vulgare/compactum*), hulled wheat (*Triticum spelta/dicoccum/monococcum*), oats (*Avena sativa*) and rye (*Secale cereale*) were used as secondary crops (Grabowski 2011, 2014). Changes in crop cultivation are then documented during the Migration Period in southern Sweden (Grabowski 2011; Widgren & Pedersen 2011). From the Roman Iron Age to the Migration Period, oats and rye significantly increased, becoming major components of agriculture during that period in southern Sweden (Grabowski 2011; Widgren & Pedersen 2011). Hulled barley remained the primary crop throughout the Iron Age, whereas naked barley was found in small quantities during the beginning of the Iron Age and then decreased steadily (Grabowski 2011). Wheat was continuously cultivated in the Iron Age, whereas the speltoid wheat decreased during the Migration and Vendel periods (Grabowski 2011). Grabowski (2011) highlighted that wheat, bread wheat or speltoid wheat appeared in small quantities during the Iron Age in southern Scandinavia and suggested that wheat might have been used as a luxury product. Consequently, an obvious shift in crop cultivation regime occurred at the onset of the Migration Period in southern Sweden (Grabowski 2011, 2014).

Changes in crop cultivation could have affected animal husbandry, as crop cultivation is closely connected to animal husbandry through activities such as manuring, ploughing, and grazing (Macheridis 2022: p. 27). Zooarchaeological studies conducted in southern Sweden have shed light on changes in animal abundances during the mid-first millennium AD (Macheridis 2022). Cattle and sheep dominated during the Iron Age in southern Sweden. However, cattle bone abundances decreased significantly in the late 6th century AD, in the transitional period between the late Migration and Early Vendel periods (Macheridis 2022). Meanwhile, sheep/goat bone assemblages increased on Gotland and Öland during the latter part of Early Iron Age, and the presence of pig skeletal remains increased at the end of the Iron Age (Welinder *et al*. 1998: p. 369; Macheridis 2022). During the late 5th to early 6th century AD, a triadic mixed animal husbandry system, centred around cattle, sheep/goats and pigs, was established (Macheridis 2022: p. 86). Macheridis (2022) suggests that the persistence of cattle-based husbandry was influenced by sociopolitical turmoil, possibly linked to the AD 536/540 event, as continuing with a proven strategy might have offered stability during crisis. Additionally, she posits that societal reorganization following the climatic event might have prompted changes in animal husbandry practices, with the transition to mixed animal husbandry potentially offering greater sustainability than a cattle-based system (Macheridis 2022: p. 86). However, certain sites, like Gårdlösa in Scania, did not adopt this triadic shift and maintained a focus on cattle-based economies (Macheridis 2022: p. 98), providing evidence of different strategies taken during the climatic event.

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Besides changes in crop and animal husbandry, an agricultural decline and subsequent forest regrowth have been observed during the middle and late 6th century in Sweden (Price & Gräslund 2015). Berglund (2003) claimed that agriculture, consisting of pasturing and crop cultivation, stagnated during the Migration Period. Additionally, woodland expansion has also been recorded in formerly cultivated areas around AD 200–500 (Berglund 1969: p. 17; Berglund *et al.* 1991; Gaillard *et al.* 1994). Pollen diagrams confirm this observation, showing reduced human impact and grazing pressure as well as the abandonment of pastures, particularly on the Baltic islands and in the eastern part of Sweden (Engelmark & Wallin 1985; Gaillard *et al.* 1994; Lagerås *et al.* 1995; Widgren & Pedersen 2011; Widgren 2012).

Specifically, pollen data from the Axlarp region in southern Sweden show a farming stagnation at AD 500, whereas data from lake Femtingagölen, located 10 km away, identified a regression phase later, at around AD 600–700 (Lagerås *et al.* 1995; Lagerås 1996). Moreover, pollen records from central and southern Sweden reveal a decrease in palynological richness correlated with the agrarian and settlement crisis during AD 500–700 (Engelmark & Wallin 1985; Berglund *et al.* 2008). Fredh *et al.* (2013) studied land-use changes in the uplands of southern Sweden, suggesting that palynological diversity increased from AD 350 to 550 in the studied area, coinciding with the intensified land use, followed by a decrease during AD 550–750, indicating land-use regression and agricultural land abandonment (Fredh *et al.* 2013). Multi-proxy studies, incorporating pollen analysis, bog surface indicators, and aeolian sediment influx on Store Mosse Bog and Undarsmosse in south-western Sweden, suggest an agricultural decline around AD 450 and 500, and from AD 750 to 950 (de Jong & Lagerås 2011; de Jong 2007: p. 15).

Settlement and demographic decline

The stagnation of cultivation and the abandonment of the agricultural soils relate to the settlement abandonments (Price & Gräslund 2015). Settlements expanded during the Roman Iron Age, but many were abandoned in the middle of the first millennium AD across various regions in Sweden (Stenberger 1933; Widgren 1983, 2012; Ambrosiani 1984; Widgren & Pedersen 2011; Gräslund & Price 2012). Göthberg (2007: p. 440) pinpointed a sharp decline in settlements at AD 600–700, whereas other researchers argued that the decline began as early as the 5th century AD (Svedjemo 2014). This phenomenon was particularly evident in Gotland, Öland, Östergötland, Västergötland, Uppland, and Hälsingland compared with other areas in Sweden (Widgren 1983, 2012; Engelmark & Wallin 1985; Welinder *et al.* 1998: p. 305; Widgren & Pedersen 2011; Löwenborg 2012; Gräslund & Price 2012).

Specifically, estimations suggest a significant reduction in the number of sites in Uppland, ranging between 60 and 75%, while the population decreased by 50% in the 6th century (Göthberg 2007: p. 444; Gräslund & Price 2012). Nerman (1963: p. 19) suggested a 50% reduction in the number of graves on Gotland during the latter part of the Migration Period, around AD 475–550, while Carlsson (1984) estimated a more modest decline of 10% in settlements. A recent study by Svedjemo (2014) proposed a decline in settlements and population on Gotland by 30–50%, which means that around 1000–1200 farms/settlements were abandoned. In southern Sweden, it is estimated that settlements and farms experienced a reduction of 20% (Schmidt Sabo & Söderberg 2019: p. 17).

Löwenborg (2012) delved into demographic changes in Västmanland using burial ground datasets and suggested that most sites were abandoned between the end of the Migration Period and the onset of the Early Vendel Period. In southern Sweden, distinct declines in settlement numbers were noted from the late 5th century until the late 6th century, reaching their lowest point between AD 550–700 (Schmidt Sabo & Söderberg 2019: p. 15). However, in south-western Scania, a decline in coastal areas was identified earlier, during the 4th century (Söderberg *et al.* 2021: p. 275). In the area of Lund, a sharp decline was observed from AD 400 to 700, whereas this decline was less pronounced in the Malmö area (Schmidt Sabo & Söderberg 2019: p. 17). Söderberg *et al.* (2021) investigated long-term land-use and settlement changes in a forested ridge of Linderödsåsen and on lowland plains in southern Sweden, noting a clear decline in the upland area during the 6th century, contrasting with in the plain area. Around AD 700, they suggested an expansion period in both regions, lasting until AD 1100 (Söderberg *et al.* 2021: p. 269). However, radiocarbon data from southern Sweden indicate an expansion into upland areas from AD 200 to 600, synchronous with abandonment in central and marginal areas around AD 650 (Friman & Lagerås 2022). Friman & Lagerås (2022) considered this population decline at AD 650 as a belated impact of the AD 536/540 event and plague.

In some areas of northern Fennoscandia and Finland, a settlement expansion or stability is evident during the 6th century AD (Tvauri 2014). The decrease in settlements is less noticeable in western Sweden and in central uppland, and with evidence even suggesting an expansion of settlements in northern Sweden (Baudou 1978: p. 20; Liedgren 1992; Widgren 1997: p. 58, Widgren 2012; Welinder *et al.* 1998: p. 306; Widgren & Pedersen 2011). The Migration Period has generally been seen as a time of expansion in most areas of northern Sweden that were affected by sedentary farming (Baudou 1978; Engelmark 1978: p. 46; Ramqvist 1983; Liedgren 1992; Widgren 1997: p. 59). Pollen data from Ångermanland showed an increase in sedentary farming settlements in the 6th century (Wallin 1996). Liedgren (1992), in his dissertation about the development of sedentary agrarian settlement in

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northern Hälsingland, showed that most farms were established during the Migration Period. By the end of the Migration Period, around 600–700 farms might have existed in the area, although they were abandoned during the Vendel Period (Liedgren 1992: p. 222).

On Öland, Fallgren (2006) challenged the previous research suggesting discontinuity in settlement patterns and land use, proposing instead an unbroken continuity of settlement development. According to Fallgren (2006: p. 187), only a few villages in northern Öland might have been abandoned before the Viking Age, although the exact chronology remains uncertain. Conversely, Göthberg (2007: p. 440) proposed that both continuity and discontinuity could be observed in the settlements in Uppland, emphasizing that perceptions of continuity or discontinuity depend on one's perspective. Therefore, further research is needed to investigate the increase or decrease in settlements across different areas of Sweden during this period.

Discussion

As described above, climate change has been considered as a driving factor for the observed changes in the archaeological record in the middle of the first millennium AD in Sweden since as early as the 1950s and 1960s (Arrhenius 1955; Almgren 1957; Königsson 1968). In recent years, the availability of high-resolution climatic and environmental reconstructions has significantly expanded, offering greater insight into the role of climate change in shaping past human societies (Burke *et al.* 2021; Gundersen 2021: p. 58). Archaeological research based on detailed climatic datasets has revitalized the hypothesis that climate change, particularly the AD 536/540 event, played a significant role in the observed changes in the archaeological record in Iron Age Sweden (Gräslund 2007; Gräslund & Price 2012; Price & Gräslund 2015). This approach can provide new insights into understanding of the societal dynamics (Burke *et al.* 2021; Gundersen 2021: p. 76). However, as climate change has been considered to have had a profound impact on Iron Age societies, environmental determinism as a disadvantage of such interpretations is once again discussed in Swedish archaeological research and generally in archaeological research (Näsman 2012; Widgren 2012; Moreland 2018). Some researchers argue that revisiting the question of whether this climatic event influenced societies during the mid-first millennium AD feels like a repetition and a resurgence of environmental determinism in archaeological research in the context of contemporary concern about the impact of climate change on our planet (Näsman 2012; Moreland 2018). Research should not dismiss the relationship between climate and societal change outright by accusing it of determinism. Instead, it should seek nuanced approaches to disentangling these relationships from overly simplistic causal interpretations (Molloy 2022).

Certainly, the research into the impact of climate on past societies faces persistent challenges (Davis 2020), and it is true that the criticism against these studies will remain valid until the research addresses its fundamental hurdles (Gundersen 2019, 2021). Concerns primarily revolve around establishing causal links between the climate and societal changes, which emerge from the issue of comparing broadly dated archaeological data with a precisely dated climatic event (Näsman 2012; Moreland 2018). The relationship between climate change and human responses is not linear and it cannot be assumed, it must be estimated and proved in the context of the specific culture and the timing of the specific events connected to the climate fluctuations (Rivera-Collazo 2022). Chronological correlation is essential, providing evidence for links between environmental and societal interactions. Increased chronological precision could dispel doubts about conflating concurrence with causation (Widgren 2012; Contreras 2016; Moreland 2018; Degroot *et al.* 2022). Enhancing chronological and spatial resolution is paramount for future studies to investigate long-term changes and comprehensively understand the impact of climate change on societies, considering the limitations of chronological precision and methodologies (Caseldine & Turney 2010; Contreras 2016; Ion 2019; Gjerpe 2021; Degroot *et al.* 2022). Proxies have advantages but also limitations, e.g. tree-ring records provide high temporal resolution, whereas marine sediment records provide longer but lower resolution records (Caseldine & Turney 2010; Davis 2020; Degroot *et al.* 2022). Combining multi-proxy data can mitigate these limitations (Davis 2020; Molloy 2022). Thus, articulating the relationship between climate change and societal responses requires multi-proxy data alongside robust chronological dating of the observed archaeological changes within the context of climatic events (Davis 2020; Rivera-Collazo 2022).

Arponen *et al.* (2019) delved into the contours of the environmental determinism debate, which intersected with the ongoing discourse about causality and determinism in archaeological research (Samuels 2019). They highlighted that the crux of the matter lies in research designs centred on detecting parallel alterations between environmental/climatic and archaeological data (Arponen *et al.* 2019). In response, Ion (2019) contended that the issue stemmed from overly simplistic hypotheses, where complex environmental, climatic, and archaeological data translated into simple causal interpretation. A proposed path forward involves a shift in archaeological research towards anthropological approaches that investigate what creates social vulnerability or adjustability to the climatic hazards (Arponen *et al.* 2019: p. 9; Ion 2019). The concepts of resilience, adaptation, and vulnerability are widely employed in archaeological research to understand human responses to climate change (Redman 2005; Degroot *et al.* 2022). Gundersen (2021: p. 80) highlighted that the development of analytical frameworks is what is missing from understanding the impact of the AD 536/540 event on the Scandinavian societies and its

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importance lies in the risk of misinterpreting the concurrence with causation. Moving beyond the environmental determinism debate requires the development of analytical frameworks, with vulnerability, resilience, and adaptation emerging as pivotal tools (Gundersen 2021). Gundersen (2021: p. 85) further discussed agricultural vulnerability as a vital aspect of understanding the effect of AD 536/540 on Swedish Iron Age societies.

A theoretical framework in archaeological human-environment interactions is essential, but equally significant is the archaeological evidence for climatic impact on human societies and societal vulnerability (Hussain & Riede 2020). Understanding the link between climatic and archaeological data demands arguments grounded in various lines of evidence (Kintigh & Ingram 2018). While the AD 536/540 event has been connected with famine, population decline, settlement abandonments, and epidemics like the Justinian plague and ergotism in Swedish Iron Age societies (Gräslund & Price 2012; Bondeson & Bondesson 2014; Tvauri 2014), the evidence linking these consequences to climatic event remains debatable (Gundersen 2021). Thus, what is still missing in the Fimbulwinter research is evidence to confirm or refute possible connections between these changes and the climate events.

The notion of agricultural vulnerability, supported by prior research (Tvauri 2014; Gundersen 2019, 2021), suggests that societies heavily dependent on agricultural resources were probably affected the most, as this cooling event could have shortened the growing season and significantly impacted food production capacity. However, understanding the full extent of this vulnerability requires determination of the degree to which Iron Age societies in Sweden relied on terrestrial-based diets (Gundersen 2021). Bioarchaeological and biomolecular methods can be pivotal in testing hypotheses and provide valuable evidence from well-dated skeletal remains, crucial for understanding dietary changes, shifts in subsistence strategies, alterations in husbandry practices, occurrences of malnutrition and diseases, and migration patterns amidst changing environmental conditions (Knudson *et al.* 2015; Robbins Schug *et al.* 2018, 2023). For example, stable isotope analysis can offer insights into the degree of reliance on terrestrial resources. Analysing data from various geographic regions and spanning periods before, during, and after the climatic event can deepen our understanding of human responses to climate fluctuations across diverse settings (Harrod & Martin 2013: p. 7; Robbins Schug *et al.* 2018, 2023). The key to understanding the impact of this event lies in comprehending regional variability. While some studies have used regional variability as a reason to dispute the Fimbulwinter theory, further research at the regional level will provide additional insights, as climatic events can cause different reactions depending on local preconditions (Gundersen 2021). Local climatic and regional data during the first millennium AD are needed to grasp the local magnitude and impact (Rivera-Collazo 2022; Wastegård 2022). These investigations require high-resolution palaeoclimate data, reliable chronology, and preserved skeletal remains (Harrod & Martin 2013: p. 7; Knudson *et al.* 2015; Robbins Schug *et al.* 2018, 2023). Despite these prerequisites, bioarchaeological and biomolecular studies have the potential to provide significant information about the impact of climate change on the studied societies (Robbins Schug *et al.* 2018, 2023), and testing, in this case, if the reliance on agricultural resources through isotopes can be linked to regions that are affected the most.

Conclusions

This review paper presented the research development of the AD 536/540 event and its possible impacts, with a focus on Swedish Iron Age societies, utilizing published climatic and archaeological data. The consideration of climate change as a contributing factor to the observed changes in the Swedish archaeological record during the middle of the first millennium AD dates back to the 1950s and 1960s (Arrhenius 1955; Almgren 1957; Königsson 1968). Recent advancements, including the availability of high-resolution climatic data and evidence confirming the existence of the AD 536/540 event (Baillie 1994, 2008; Larsen *et al.* 2008; Churakova *et al.* 2014; Sigl *et al.* 2015; Büntgen *et al.* 2016; Toohey *et al.* 2016; Dull *et al.* 2019; Helama *et al.* 2019), have reignited discussions in archaeological research regarding the impact of this event on Swedish Iron Age societies (Gräslund 2007; Gräslund & Price 2012; Löwenborg 2012; Arrhenius 2013; Bondeson & Bondesson 2014; Tvauri 2014; Price & Gräslund 2015; Zachrisson 2017; Gundersen 2019, 2021; Solheim & Iversen 2019). However, some limitations have resulted in criticism of this hypothesis (Näsman 2012; Moreland 2018). Overcoming these limitations is essential for future studies, as understanding past human–environment interactions not only sheds light on human past but also informs predictions of responses and adaptive strategies to contemporary and future climate change (Douglas *et al.* 2016). Addressing these limitations requires the development of analytical frameworks, improvement of chronological correlations between archaeological and environmental data, the acquisition of local climatic data from Sweden, the examination of periods before, during, and after climatic impact, and the gathering of additional evidence through bioarchaeological and biomolecular analyses, as discussed above. These are crucial for understanding the impact of AD 536/540 event on Swedish societies.

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Author contributions. – EA, KL and JL conceived and designed the study, EA wrote the paper while review and editing were done by EA, KL and JL.

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References

Almgren, B. 1957: Vallhagar: byn och boken. *Fornvännen 52*, 227–246.

Ambrosiani, B. 1984: Settlement expansion – settlementt contraction: a question of war, plague, ecology or climate? *In* Mörner, N. A. & Karlen, W. (eds.): *Climatic Changes on a Yearly to Millennial Basis: Geological, Historical and Instrumental Records*, 241–247. Springer – Science and Business Media, B.V, Dordrecht.

Andersson, S., Rosqvist, G., Leng, M. J., Wastegård, S. & Blaauw, M. 2010: Late Holocene climate change in central Sweden inferred from lacustrine stable isotope data. *Journal of Quaternary Science 25*, 1305–1316.

Arjava, A. 2005: The mystery cloud of 536 CE in the Mediterranean sources. *Dumbarton Oaks Papers 59*, 73–94.

Arponen, V. P. J., Dörfler, W., Feeser, I., Grimm, S., Groß, D., Hinz, M., Knitter, D., Müller-Scheeßel, N., Ott, K. & Ribeiro, A. 2019: Environmental determinism and archaeology. Understanding and evaluating determinism in research design. *Archaeological Dialogues 26*, 1–9.

Arrhenius, O. 1955: The Iron Age settlements on Gotland and the nature of the soil. *In* Stenberger, M. (ed.): *Vallhagar II*, 1053–1064. Ejnar Munksgaards forlag, Copenhagen.

Arrhenius, B. 2013: Helgö in the shadow of the dust veil 536-37. *Journal of Archaeology and Ancient History 5*, 1–14.

Arthur, F., Hatlestad, K., Lindholm, K.-J., Loftsgarden, K., Löwenborg, D., Solheim, S., Roche, D. M. & Renssen, H. 2024: The impact of volcanism on Scandinavian climate and human societies during the Holocene: insights into the Fimbulwinter eruptions (536/540 AD). *The Holocene 34*, 619–633.

Axboe, M. 1999: The year 536 and the Scandinavian gold hoards. *Medieval Archaeology 43*, 186–188.

Axboe, M. 2001: Amulet pendants and a darkened sun. On the function of the gold bracteates and a possible motivation for the large gold hoards. *In* Magnus, B. (ed.): *Roman Gold and the Development of the Early Germanic Kingdoms: Aspects of Technical, Socio-Political, Socio-Economic, Artistic and Intellectual Development, A.D. 1–550*, 119–136. Symposium in Stockholm 14–16th November 1997, Conference 51. Kungliga Vitterhets Historie och Antikvitets Akademien, Stockholm.

Baillie, M. G. 1991: Marking in marker dates: towards an archaeology with historical precision. *World Archaeology 23*, 233–243.

Baillie, M. G. 1994: Dendrochronology raises questions about the nature of the AD 536 dust-veil event. *The Holocene 4*, 212–217.

Baillie, M. G. 2008: Proposed re-dating of the European ice core chronology by seven years prior to the 7th century AD. *Geophysical Research Letters 35*, L15813, https://doi.org/10.1029/2008GL034755.

Baudou, E. 1978: Archaeological investigations at L. Holmsjön, Medelpad. *In* Baudou, E., Engelmark, R., Olsson, I. U. & Renberg, I. (eds.): *Early Norrland II. Archaeological and Palaeoecological Studies in Medelpad, N. Sweden*, 1–24. Kungliga Vitterhets Historie och Antikvitets Akademien, Stockholm.

Berglund, B. E. 1969: Vegetation and human influence in South Scandinavia during Prehistoric time. *In* Berglund, B. (ed.): *Impact of Man on the Scandinavian Landscape During the Late Post-Glacial*, 9–28. Symposium on Öland 11–12 June 1968. *Oikos, Acta Oecologica Scandinavica 12*. Munksgaard, Copenhagen.

Berglund, B. E. 2003: Human impact and climate changes—synchronous events and a causal link? *Quaternary International 105*, 7–12.

Berglund, B. E., Gaillard, M. J., Björkman, L. & Persson, T. 2008: Long-term changes in floristic diversity in southern Sweden: palynological richness, vegetation dynamics and land-use. *Vegetation History and Archaeobotany 17*, 573–583.

Berglund, B. E., Malmer, N. & Persson, T. 1991: Landscape-ecological aspects of long-term changes in the Ystad area. *Ecological Bulletins 41*, 405–424.

Bergman, J. 2005: *Tree-limit ecotonal response to Holocene climate change in the Scandes Mountains of west-central Sweden*. Ph.D. thesis, Lund University, 40 pp.

Björck, S. & Clemmensen, L. B. 2004: Aeolian sediment in raised bog deposits, Halland, SW Sweden: a new proxy record of Holocene winter storminess variation in southern Scandinavia? *The Holocene 14*, 677–688.

Bondeson, L. & Bondesson, T. 2014: On the mystery cloud of AD 536, a crisis in dispute and epidemic ergotism: a linking hypothesis. *Danish Journal of Archaeology 3*, 61–67.

Borgmark, A. & Wastegård, S. 2008: Regional and local patterns of peat humification in three raised peat bogs in Värmland, south-central Sweden. *GFF 130*, 161–176.

Breeze, A. 2016: Arthur's battles and the volcanic winter of 536–37. *Northern History 53*, 161–172.

Briffa, K. R., Bartholin, T. S., Eckstein, D., Jones, P. D., Karlén, W., Schweingruber, F. H. & Zetterberg, P. 1990: A 1,400-year tree-ring record of summer temperatures in Fennoscandia. *Nature 346*, 434–439.

Briffa, K. R., Jones, P. D., Bartholin, T. S., Eckstein, D., Schweingruber, F. H., Karlen, W., Zetterberg, P. & Eronen, M. 1992: Fennoscandian summers from AD 500: temperature changes on short and long timescales. *Climate Dynamics 7*, 111–119.

Büntgen, U. and 38 others 2022: Global wood anatomical perspective on the onset of the Late Antique Little Ice Age (LALIA) in the mid-6th century CE. *Science Bulletin 67*, 2336–2344.

Büntgen, U., Arseneault, D., Boucher, É., Churakova, O. V., Gennaretti, F., Crivellaro, A., Hughes, M. K., Kirdyanov, A. V., Klippel, L., Krusic, P. J., Linderholm, H. W., Ljungqvist, F. C., Ludescher, J., McCormick, M., Myglan, V. S., Nicolussi, K., Piermattei, A., Oppenheimer, C., Reinig, F., Sigl, M., Vaganov, E. A. & Esper, J. 2020: Prominent role of volcanism in Common Era climate variability and human history. *Dendrochronologia 64*, 125757, https://doi.org/10.1016/j.dendro.2020.125757.

Büntgen, U., Myglan, V. S., Charpentier Ljungqvist, F., McCormick, M., Di Cosmo, N., Sigl, M., Jungclaus, J., Wagner, S., Krusic, P., Esper, J., Kaplan, J. O., de Vaan, M. A. C., Luterbacher, J., Wacker, L., Tegel, W. & Kirdyanov, A. V. 2016: Cooling and societal change during the Late Antique Little Ice Age from 536 to around 660 AD. *Nature Geoscience 9*, 231–236.

Büntgen, U., Myglan, V. S., Charpentier Ljungqvist, F., McCormick, M., Di Cosmo, N., Sigl, M., Jungclaus, J., Wagner, S., Krusic, P., Esper, J., Kaplan, J. O., de Vaan, M. A. C., Luterbacher, J., Wacker, L., Tegel, W. & Kirdyanov, A. V. 2017: Reply to 'Limited Late Antique cooling'. *Nature Geoscience 10*, 243.

Burke, A., Peros, M. C., Wren, C. D., Pausata, F. S. R., Riel-Salvatore, J., Moine, O., de Vernal, A., Kageyama, M. & Boisard, S. 2021: The archaeology of climate change: the case for cultural diversity. *Proceedings of the National Academy of Sciences of the United States of America 118*, e2108537118, https://doi.org/10.1073/pnas.2108537118.

Carlsson, D. 1977: Den folkvandringstida ödeläggelsen på Gotland. *Gotländskt Arkiv 1977*, 27–46.

Carlsson, D. 1984: Change and continuity in the Iron Age settlement of Gotland. *In* Kristiansen, K. (ed.): *Settlement and Economy in Later Scandinavian Prehistory*, 129–153. *BAR International Series 211*, Oxford.

Carlsson, D. 1988: Den folkvandringstida krisen. En fråga om fältmaterialets representativitet. *In* Näsman, U. & Lund, J. (eds.): *Folkevandringstiden i Norden. En krisetid mellem ældre og yngre jernalder*, 33–42. Rapport fra et bebyggelsearkæologisk forskersymposium i Degerhamn, Öland., d. 2.-4. Oktober 1985. Aarhus Universitetsforlag, Aarhus.

Caseldine, C. J. & Turney, C. 2010: The bigger picture: towards integrating palaeoclimate and environmental data with a history of societal change. *Journal of Quaternary Science 25*, 88–93.

Churakova, O. V., Bryukhanova, M. V., Saurer, M., Boettger, T., Naurzbaev, M. M., Myglan, V. S., Vaganov, E. A., Hughes, M. K. & Siegwolf, R. T. 2014: A cluster of stratospheric volcanic eruptions in the AD 530s recorded in Siberian tree rings. *Global and Planetary Change 122*, 140–150.

15023885, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/bor.12672 by Statens Beredning, Wiley Online Library on [09/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Contreras, D. A. 2016: Correlation is not enough: building better arguments in the archaeology of human-environment interactions. *In* Contreras, D. (ed.): *The Archaeology of Human-Environment Interactions. Strategies for Investigating Anthropogenic Landscapes, Dynamic Environments, and Climate Change in the Human Past*, 17–36. Routledge, New York.

D'Arrigo, R., Frank, D., Jacoby, G. & Pederson, N. 2001: Spatial response to major volcanic events in or about AD 536, 934 and 1258: frost rings and other dendrochronological evidence from Mongolia and northern Siberia: comment on R. B. Stothers, 'volcanic dry fogs, climate cooling, and plague pandemics in Europe and the Middle East' (climatic change, 42, 1999). *Climatic Change 49*, 239–246.

Davis, D. S. 2020: Studying human responses to environmental change: trends and trajectories of archaeological research. *Environmental Archaeology 25*, 367–380.

Degroot, D., Anchukaitis, K. J., Tierney, J. E., Riede, F., Manica, A., Moesswilde, E. & Gauthier, N. 2022: The history of climate and society: a review of the influence of climate change on the human past. *Environmental Research Letters 17*, 103001, https://doi.org/10.1088/1748-9326/ac8faa.

Diaz, H. & Trouet, V. 2014: Some perspectives on societal impacts of past climatic changes. *History Compass 12*, 160–177.

van Dijk, E., Jungclaus, J., Lorenz, S., Timmreck, C. & Krüger, K. 2022: Was there a volcanic-induced long-lasting cooling over the Northern Hemisphere in the mid-6th–7th century? *Climate of the Past 18*, 1601–1623.

Douglas, P. M., Demarest, A. A., Brenner, M. & Canuto, M. A. 2016: Impacts of climate change on the collapse of lowland Maya civilization. *Annual Review of Earth and Planetary Sciences 44*, 613–645.

Drake, B. L. 2012: The influence of climatic change on the Late Bronze Age Collapse and the Greek Dark Ages. *Journal of Archaeological Science 39*, 1862–1870.

Drake, B. L. 2017: Changes in North Atlantic oscillation drove population migrations and the collapse of the Western Roman Empire. *Scientific Reports 7*, 1227, https://doi.org/10.1038/s41598-017-01289-z.

Dull, R. A., Southon, J. R., Kutterolf, S., Anchukaitis, K. J., Freundt, A., Wahl, D. B., Sheets, P., Amaroli, P., Hernandez, W., Wiemann, M. C. & Oppenheimer, C. 2019: Radiocarbon and geologic evidence reveal Ilopango volcano as source of the colossal 'mystery' eruption of 539/40 CE. *Quaternary Science Reviews 222*, 105855, https://doi.org/10.1016/j.quascirev.2019.07.037.

Engelmark, R. 1978: The comparative vegetational history of inland and coastal sites in Medelpad, N Sweden, during the Iron Age. *Early Norrland 11*, 25–62.

Engelmark, R. & Wallin, J. E. 1985: Pollen analytical evidence for Iron Age agriculture in Hälsingland, central Sweden. *Archaeology and Environment 4*, 353–366.

Esper, J., Büntgen, U., Timonen, M. & Frank, D. C. 2012: Variability and extremes of northern Scandinavian summer temperatures over the past two millennia. *Global and Planetary Change 88*, 1–9.

Fallgren, J. H. 2006: *Kontinuitet och förändring: bebyggelse och samhälle på Öland 200–1300 e Kr*. Ph.D. thesis, Uppsala Universitet, 224 pp.

Fell, H. G., Baldini, J. U., Dodds, B. & Sharples, G. J. 2020: Volcanism and global plague pandemics: towards an interdisciplinary synthesis. *Journal of Historical Geography 70*, 36–46.

Ferris, D. G., Cole-Dai, J., Reyes, A. R. & Budner, D. M. 2011: South Pole ice core record of explosive volcanic eruptions in the first and second millennia AD and evidence of a large eruption in the tropics around 535 AD. *Journal of Geophysical Research 116*, D17308, https://doi.org/10.1029/2011JD015916.

Flink, G. 1986: Ölands stensträngsområden och den justinianska pesten. *Bebyggelsehistorisk tidskrift Nordic Journal of Settlement History and Built Heritage 11*, 121–135.

Fredh, D., Broström, A., Rundgren, M., Lagerås, P., Mazier, F. & Zillen, L. 2013: The impact of land-use change on floristic diversity at regional scale in southern Sweden 600 BC–AD 2008. *Biogeosciences 10*, 3159–3173.

Friman, B. & Lagerås, P. 2022: From Neolithic boom-and-bust to Iron Age peak and decline: population and settlement dynamics in southern Sweden inferred from summed radiocarbon dates. *European Journal of Archaeology 26*, 168–188.

Fuks, D., Ackermann, O., Ayalon, A., Bar-Matthews, M., Bar-Oz, G., Levi, Y., Maeir, A. M., Zilberman, T. & Safrai, Z. 2017: Dust clouds, climate change and coins: consiliences of palaeoclimate and economy in the Late Antique southern Levant. *Levant 49*, 205–223.

Gaillard, M. J., Birks, H. J. B., Emanuelsson, U., Karlsson, S., Lagerås, P. & Olausson, D. 1994: Application of modern pollen/land-use relationships to the interpretation of pollen diagrams—reconstructions of land-use history in south Sweden, 3000-0 BP. *Review of Palaeobotany and Palynology 82*, 47–73.

Ganiev, R. T. 2014: The climate cooling of 536–545 AD and the rise of the Turkic Empire. *Life Science Journal 11*, 496–499.

Gill, R. B. 2000: *The Great Maya Droughts: Water, Life, and Death*. 464 pp. University of New Mexico Press, Albuquerue.

Gjerpe, L. E. 2021: The 536 Dust Veil Event and the long 6th century. *In Situ Archaeologica 15*, 31–58.

Göthberg, H. 2007: *Hus och bebyggelse i Uppland: delar av förhistoriska sammanhang*. 472 pp. Riksantikvarieämbetet, Uppsala.

Grabowski, R. 2011: Changes in cereal cultivation during the Iron Age in southern Sweden: a compilation and interpretation of the archaeobotanical material. *Vegetation History and Archaeobotany 20*, 479–494.

Grabowski, R. 2014: *Cereal husbandry and settlement: expanding archaeobotanical perspectives on the southern Scandinavian Iron Age*. Ph.D. thesis, Umeå Universitet, 112 pp.

Gräslund, B. 1973: Äring, näring, pest och salt. *Tor: tidskrift för nordisk fornkunskap XV*, 274–293.

Gräslund, B. 2007: Fimbulvintern, Ragnarök och klimatkrisen år 536-537 e. Kr. *Saga och sed: Kungliga Gustav Adolfs akademiens årsbok 2007*, 93–123.

Gräslund, B. & Price, N. 2012: Twilight of the gods? The 'dust veil event' of AD 536 in critical perspective. *Antiquity 86*, 428–443.

Grudd, H., Briffa, K. R., Karlén, W., Bartholin, T. S., Jones, P. D. & Kromer, B. 2002: A 7400-year tree-ring chronology in northern Swedish Lapland: natural climatic variability expressed on annual to millennial timescales. *The Holocene 12*, 657–665.

Gundersen, I. M. 2019: The Fimbulwinter theory and the 6th century crisis in the light of Norwegian archaeology: towards a human-environmental approach. *Primitive Tider 21*, 101–119.

Gundersen, I. M. 2021: *Iron Age vulnerability. The Fimbulwinter hypothesis and the archaeology of the inlands*. Ph.D. thesis, University of Oslo, 436 pp.

Gunn, J. D. 2000: The years without summer: tracing AD 536 and its aftermath. *BAR International Series 872*, 170 pp.

Gunnarson, B. E., Borgmark, A. & Wastegård, S. 2003: Holocene humidity fluctuations in Sweden inferred from dendrochronology and peat stratigraphy. *Boreas 32*, 347–360.

Gutsmiedl-Schümann, D., Päffgen, B., Schwarzberg, H., Keller, M., Rott, A. & Harbeck, M. 2018: Digging up the plague: a diachronic comparison of aDNA confirmed plague burials and associated burial customs in Germany. *Praehistorische Zeitschrift 92*, 405–427.

Harrod, R. & Martin, D. L. 2013: *Bioarchaeology of Climate Change and Violence: Ethical Considerations*. 161 pp. Springer, New York.

Haug, G. H., Gunther, D., Peterson, L. C., Sigman, D. M., Hughen, K. A. & Aeschlimann, B. 2003: Climate and the collapse of Maya civilization. *Science 299*, 1731–1735.

Helama, S., Arppe, L., Uusitalo, J., Holopainen, J., Mäkelä, H. M., Mäkinen, H., Mielikäinen, K., Nöjd, P., Sutinen, R., Taavitsainen, J. P., Timonen, M. & Oinonen, M. 2018: Volcanic dust veils from sixth century tree-ring isotopes linked to reduced irradiance, primary production and human health. *Scientific Reports 8*, 1–12.

Helama, S., Jones, P. D. & Briffa, K. R. 2017a: Limited late antique cooling. *Nature Geoscience 10*, 242–243.

Helama, S., Jones, P. D. & Briffa, K. R. 2017b: Dark Ages Cold Period: a literature review and directions for future research. *The Holocene 27*, 1600–1606.

Helama, S., Saranpää, P., Pearson, C. L., Arppe, L., Holopainen, J., Mäkinen, H., Mielikainen, K., Nojd, P., Sutinen, R., Taavitsainen, J. P., Timonen, M., Uusitalo, J. & Oinonen, M. 2019: Frost rings in 1627 BC and AD 536 in subfossil pinewood from Finnish Lapland. *Quaternary Science Reviews 204*, 208–215.

15023885, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/bor.12672 by Statens Beredning, Wiley Online Library on [09/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Helbaek, H. 1955: The botany of the Vallhagar Iron Age field. *In* Stenberger, M. (ed.): *Vallhagar II*, 653–699. Ejnar Munksgaards forlag, Copenhagen.
Herschend, F. 1988: Bebyggelse och folkvandringstid på Öland. *In* Näsman, U. & Lund, J. (eds.): *Folkevandringstiden i Norden. En krisetid mellem ældre og yngre jernalder*, 43–66. Rapport fra et bebyggelsearkæologisk forskersymposium i Degerhamn, Öland, d. 2.-4. Oktober 1985. Aarhus Universitetsforlag, Aarhus.
Herschend, F. 2009: *The Early Iron Age in South Scandinavia: Social Order in Settlement and Landscape*. 449 pp. Institutionen för Arkeologi och Antik Historia, Uppsala Universitet, Uppsala.
Hirschfeld, Y. 2006: The crisis of the sixth century: climatic change, natural disasters and the plague. *Mediterranean Archaeology and Archaeometry 6*, 19–32.
Hussain, S. T. & Riede, F. 2020: Paleoenvironmental humanities: challenges and prospects of writing deep environmental histories. *WIREs Climate Change 11*, e667, https://doi.org/10.1002/wcc.667.
Ion, A. 2019: Beyond determinism. A case for complex explanations and human scale in framing archaeological causal explanations. *Archaeological Dialogues 26*, 10–12.
de Jong, R. 2007: *Stormy records from peat bogs in south-west Sweden. Implications for regional climatic variability and vegetation changes during the past 6500 years*. Ph.D. thesis, Lund University, 46 pp.
de Jong, R. & Lagerås, P. 2011: Exploring the patterns and causes of land use changes in south-west Sweden. *Vegetation History and Archaeobotany 20*, 15–27.
de Jong, R., Hammarlund, D. & Nesje, A. 2009: Late Holocene effective precipitation variations in the maritime regions of south-west Scandinavia. *Quaternary Science Reviews 28*, 54–64.
de Jong, R., Schoning, K. & Björck, S. 2007: Increased aeolian activity during humidity shifts as recorded in a raised bog in south-west Sweden during the past 1700 years. *Climate of the Past 3*, 411–422.
Kintigh, K. W. & Ingram, S. E. 2018: Was the drought really responsible? Assessing statistical relationships between climate extremes and cultural transitions. *Journal of Archaeological Science 89*, 25–31.
Kintigh, K. W., Altschul, J. H., Beaudry, M. C., Drennan, R. D., Kinzig, A. P., Kohler, T. A., Limp, W. F., Maschner, H. D. G., Michener, W. K., Pauketat, T. R., Peregrine, P., Sabloff, J. A., Wilkinson, T. J., Wright, H. T. & Zeder, M. A. 2014: Grand challenges for archaeology. *American Antiquity 79*, 5–24.
Knudson, K. J., Torres-Rouff, C. & Stojanowski, C. M. 2015: Investigating human responses to political and environmental change through paleodiet and paleomobility. *American Journal of Physical Anthropology 157*, 179–201.
Königsson, L. K. 1968: The Holocene history of the Great Alvar of Öland. *Acta Phytogeographica Suecica 55*, 198 pp.
Kostick, C. & Ludlow, F. 2015: The dating of volcanic events and their impacts upon European climate and society, 400-800 CE. *European Journal of Post-Classical Archaeologies 5*, 7–30.
Lagerås, P. 1996: Long-term history of land-use and vegetation at Femtingagölen—a small lake in the Småland Uplands, southern Sweden. *Vegetation History and Archaeobotany 5*, 215–228.
Lagerås, P., Jansson, K. & Vestbö, A. 1995: Land-use history of the Axlarp area in the Småland uplands, southern Sweden: palaeoecological and archaeological investigations. *Vegetation History and Archaeobotany 4*, 223–234.
Larsen, L. B., Vinther, B. M., Briffa, K. R., Melvin, T. M., Clausen, H. B., Jones, P. D., Siggaard-Andersen, M. L., Hammer, C. U., Eronen, M., Grudd, H., Gunnarson, B. E., Hantemirov, R. M., Naurzbaev, M. M. & Nicolussi, K. 2008: New ice core evidence for a volcanic cause of the AD 536 dust veil. *Geophysical Research Letters 35*, L04708, https://doi.org/10.1029/2007GL032450.
Liedgren, L. 1992: *Hus och gård i Hälsingland: en studie av agrar bebyggelse och bebyggelseutveckling i norra Hälsingland Kr. f-600 e. Kr*. 266 pp. Umeå Universitet, Arkeologiska Institutionen, Umeå.
Linderholm, H. W. & Gunnarson, B. E. 2005: Summer temperature variability in central Scandinavia during the last 3600 years. *Geografiska Annaler: Series A, Physical Geography 87*, 231–241.
Löwenborg, D. 2012: An Iron Age shock doctrine: did the AD 536-7 event trigger large-scale social changes in the Mälaren valley area? *Journal of Archaeology and Ancient History 4*, 1–29.
Macheridis, S. 2022: *Animal Husbandry in Iron Age Scania, with a Catalogue*. 263 pp. *(Acta Archaeologica Lundensia Series altera in 8°, Vol. 73), (Studies in Osteology, Vol. 6)*. Institutionen för Arkeologi och Antikens Historia, Lunds Universitet, Lund.
McCormick, M., Büntgen, U., Cane, M. A., Cook, E. R., Harper, K., Huybers, P., Litt, T., Manning, S. W., Mayewski, P. A., More, A. F. M., Nicolussi, K. & Tegel, W. 2012: Climate change during and after the Roman Empire: reconstructing the past from scientific and historical evidence. *Journal of Interdisciplinary History 43*, 169–220.
Molloy, B. 2022: Was there a 3.2 ka crisis in Europe? A critical comparison of climatic, environmental, and archaeological evidence for radical change during the Bronze Age–Iron Age transition. *Journal of Archaeological Research 31*, 331–394.
Moreland, J. 2018: AD536–back to nature? *Acta Archaeologica 89*, 91–111.
Näsman, U. 1988: Den folkvandringstida krisen i Sydskandinavien, inklusive Öland och Gotland. *In* Näsman, U. & Lund, J. (eds.): *Folkevandrings tiden i Norden, en krisetid mellem ældre og yngre jernalder*, 227–256. Rapport fra et bebyggelsearkæologisk forskersymposium i Degerhamn, Öland. D. 2.-4. Oktober 1985. Aarhus Iniversitetsforlag, Aarhus.
Näsman, U. 2012: Comments on "An Iron Age shock doctrine: the 536-37 event as a trigger of large scale social change in the Mälaren valley area" by Daniel Löwenborg. *Journal of Archaeology and Ancient History 4*, 5–17.
Näsman, U. & Lund, J. 1988: *Folkevandrings tiden i Norden, en krisetid mellem ældre og yngre jernalder*. 287 pp. Rapport fra et bebyggelsearkæologisk forskersymposium i Degerhamn, Öland. D. 2.-4. Oktober 1985. Aarhus Universitetsforlag, Aarhus.
Nerman, B. 1923: *En utvandring från Gotland och öns införlivande med Sveaväldet*. 70 pp. Almqvist & Wiksells boktryckeri, Uppsala.
Nerman, B. 1963: Den gotländska utvandringen och sveaväldets expansion. *In* Sjöberg, A. G. (ed.): *Historia Kring Gotland*, 15–26. Wahlström & Widstrand, Stockholm.
Newfield, T. P. 2016: Mysterious and mortiferous clouds: the climate cooling and disease burden of Late Antiquity. *Late Antique Archaeology 12*, 89–115.
Newfield, T. P. 2018: The climate downturn of 536–50. *In* White, S., Pfister, C. & Mauelshagen, F. (eds.): *The Palgrave Handbook of Climate History*, 447–493. Palgrave, London.
Nordvig, M. & Riede, F. 2018: Are there echoes of the AD 536 event in the Viking Ragnarok myth? A critical appraisal. *Environment and History 24*, 303–324.
Pettersson, B. 1955: The Vallhagar country: some natural features relating to its history. *In* Stenberger, M. (ed.): *Vallhagar I*, 20–70. Ejnar Munksgaards Forlag, Copenhagen.
Price, N. & Gräslund, B. 2015: Excavating the Fimbulwinter? Archaeology, geomythology and the climate event (s) of AD 536. *In* Reide, F. (ed.): *Past Vulnerability: Volcanic Eruptions and Human Vulnerability in Traditional Societies Past and Present*, 109–132. Aarhus Universitetsforlag, Aarhus.
Psomiadis, D., Dotsika, E., Albanakis, K., Ghaleb, B. & Hillaire-Marcel, C. 2018: Speleothem record of climatic changes in the northern Aegean region (Greece) from the Bronze Age to the collapse of the Roman empire. *Palaeogeography, Palaeoclimatology, Palaeoecology 489*, 272–283.
Rampino, M. R., Self, S. & Stothers, R. B. 1988: Volcanic winters. *Annual Review of Earth and Planetary Sciences 16*, 73–99.
Ramqvist, P. H. 1983: *Gene: on the origin, function and development of sedentary Iron Age settlement in northern Sweden*. Ph.D. thesis, Umeå Universitet, 220 pp.
Redman, C. L. 2005: Resilience theory in archaeology. *American Anthropologist 107*, 70–77.
Rick, T. C. & Sandweiss, D. H. 2020: Archaeology, climate, and global change in the age of humans. *Proceedings of the National Academy of Sciences of the United States of America 117*, 8250–8253.
Rigby, E., Symonds, M. & Ward-Thompson, D. 2004: A comet impact in AD 536? *Astronomy & Geophysics 45*, 1–23.
Rivera-Collazo, I. 2022: Environment, climate and people: exploring human responses to climate change. *Journal of Anthropological Archaeology 68*, 101460, https://doi.org/10.1016/j.jaa.2022.101460.

15023885, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/bor.12672 by Statens Beredning, Wiley Online Library on [09/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License

Robbins Schug, G., Buikstra, J. E., DeWitte, S. N., Baker, B. J., Berger, E., Buzon, M. R., Davies-Barrett, A. M., Goldstein, L., Grauer, A. L., Gregoricka, L. A., Halcrow, S. E., Knudson, K. J., Larsen, C. S., Martin, D. L., Nystrom, K. C., Perry, M. A., Roberts, C. A., Santos, A. L., Stojanowski, C. M., Suby, J. A., Temple, D. H., Tung, T. A., Vlok, M., Watson-Glen, T. & Zakrzewski, S. R. 2023: Climate change, human health, and resilience in the Holocene. *Proceedings of the National Academy of Sciences of the United States of America 120*, e2209472120, https://doi.org/10.1073/pnas.2209472120.

Robbins Schug, G., Parnell, E. K. & Harrod, R. P. 2018: Changing the climate: bioarchaeology responds to deterministic thinking about human-environmental interactions in the past. *In* Buikstra, J. (ed.): *Bioarchaeologists Speak Out: Deep Time Perspectives on Contemporary Issues*, 133–159. Springer, Cham.

Rosqvist, G., Jonsson, C., Yam, R., Karlén, W. & Shemesh, A. 2004: Diatom oxygen isotopes in pro-glacial lake sediments from northern Sweden: a 5000 year record of atmospheric circulation. *Quaternary Science Reviews 23*, 851–859.

Rundgren, M. 2008: Stratigraphy of peatlands in central and northern Sweden: evidence of Holocene climatic change and peat accumulation. *GFF 130*, 95–107.

Salzer, M. W. & Hughes, M. K. 2007: Bristlecone pine tree rings and volcanic eruptions over the last 5000 yr. *Quaternary Research 67*, 57–68.

Samuels, K. L. 2019: From determinism to accountability. Archaeology, anthropology and ethics. *Archaeological Dialogues 26*, 14–17.

Schmidt Sabo, K. & Söderberg, B. 2019: Byns vara eller icke vara, är det frågan? By och bebyggelse i sydvästra Skåne 400–1800 e. Kr. *In Situ Archaeologica 13*, 5–54.

Seger, T. 1982: The plague of Justinian and other scourges: an analysis of the anomalies in the development of the Iron Age population in Finland. *Fornvännen 77*, 184–197.

Seppä, H., Bjune, A. E., Telford, R. J., Birks, H. J. B. & Veski, S. 2009: Last nine-thousand years of temperature variability in Northern Europe. *Climate of the Past 5*, 523–535.

Sigl, M., Winstrup, M., McConnell, J. R., Welten, K. C., Plunkett, G., Ludlow, F., Büntgen, U., Caffee, M., Chellman, N., Dahl-Jensen, D., Fischer, H., Kipfstuhl, S., Kostick, C., Maselli, O. J., Mekhaldi, F., Mulvaney, R., Muscheler, R., Pasteris, D. R., Pilcher, J. R., Salzer, M., Schüpbach, S., Steffensen, J. P., Vinther, B. M. & Woodruff, T. E. 2015: Timing and climate forcing of volcanic eruptions for the past 2,500 years. *Nature 523*, 543–549.

Sjöbeck, M. 1950: *Bleking. En landskaplig Orientering*. 364 pp. Seelig & Co, Stockholm.

Snowball, I., Korhola, A., Briffa, K. R. & Koç, N. 2004: Holocene climate dynamics in Fennoscandia and the North Atlantic. *In* Battarbee, R. W., Gasse, F. & Stickley, C. E. (eds.): *Past Climate Variability Through Europe and Africa*, 465–494. Developments in Paleoenvironmental Research. Springer, Dordrecht.

Söderberg, B., Lagerås, P. & Björk, T. 2021: Gränslandets dynamik: samspelet mellan slätt och ås i nordöstra Skåne i ett långtidsperspektiv. *Fornvännen 116*, 261–280.

Solheim, S. & Iversen, F. 2019: The mid-6th century crises and their impacts on human activity and settlements in southeastern Norway. *In* Brady, N. & Theune, C. (eds.): *Settlement Change Across Medieval Europe. Old Paradigms and New Vistas*, 423–434. Sidestone Press, Leiden.

Stathakopoulos, D. 2007: Crime and punishment: the plague in the Byzantine Empire, 541–749. *In* Little, L. K. (ed.): *Plague and the End of Antiquity: The Pandemic of 541, 750*, 99–118. Cambridge University Press, Cambridge.

Stenberger, M. 1933: *Öland under äldre järnålder: en bebyggelsehistorisk undersökning*. 306 pp. Akademiens Förlag, Stockholm.

Stenberger, M. 1955: The reason for the abandonment of Vallhagar. *In* Stenberger, M. (ed.): *Vallhagar II*, 1161–1185. Ejnar Munksgaards forlag, Copenhagen.

Stothers, R. B. 1984: Mystery cloud of AD 536. *Nature 307*, 344–345.

Stothers, R. B. 1999: Volcanic dry fogs, climate cooling, and plague pandemics in Europe and the Middle East. *Climatic Change 42*, 713–723.

Stothers, R. B. & Rampino, M. R. 1983: Volcanic eruptions in the Mediterranean before AD 630 from written and archaeological sources. *Journal of Geophysical Research 88*, 6357–6371.

Svedjemo, G. 2014: *Landscape dynamics: spatial analyses of villages and farms on Gotland AD 200-1700*. Ph.D. thesis, Uppsala University, 255 pp.

Svensson, G. 1988: Bog development and environmental conditions as shown by the stratigraphy of Store Mosse mire in southern Sweden. *Boreas 17*, 89–111.

Toohey, M., Krüger, K., Sigl, M., Stordal, F. & Svensen, H. 2016: Climatic and societal impacts of a volcanic double event at the dawn of the Middle Ages. *Climatic Change 136*, 401–412.

Tvauri, A. 2014: The impact of the climate catastrophe of 536–537 AD in Estonia and neighbouring areas. *Estonian Journal of Archaeology 18*, 30–56.

Wagner, D. M., Klunk, J., Harbeck, M., Devault, A., Waglechner, N., Sahl, J. W., Enk, J., Birdsell, D. N., Kuch, M., Lumibao, C., Poinar, D., Pearson, T., Fourment, M., Golding, B., Riehm, J. M., Earn, D. J., Dewitte, S., Rouillard, J. M., Grupe, G., Wiechmann, I., Bliska, J. B., Keim, P. S., Scholz, H. C., Holmes, E. C. & Poinar, H. 2014: Yersinia pestis and the plague of Justinian 541–543 AD: a genomic analysis. *The Lancet Infectious Diseases 14*, 319–326.

Wallin, J. E. 1996: History of sedentary farming in Ångermanland, northern Sweden, during the Iron Age and Medieval period based on pollen analytical investigations. *Vegetation History and Archaeobotany 5*, 301–312.

Wanner, H., Beer, J., Bütikofer, J., Crowley, T. J., Cubasch, U., Flückiger, J., Goosse, H., Grosjean, M., Joos, F., Kaplan, J. O., Küttel, M., Müller, S. A., Prentice, I. C., Solomina, O., Stocker, T. F., Tarasov, P., Wagner, M. & Widmann, M. 2008: Mid-to Late Holocene climate change: an overview. *Quaternary Science Reviews 27*, 1791–1828.

Wastegård, S. 2022: The Holocene of Sweden – a review. *GFF 144*, 126–149.

Weiss, H., Courty, M. A., Wetterstrom, W., Guichard, F., Senior, L., Meadow, R. & Curnow, A. 1993: The genesis and collapse of third millennium north Mesopotamian civilization. *Science 261*, 995–1004.

Welinder, S., Pedersen, E. A. & Widgren, M. 1998: *Det svenska jordbrukets historia. Jordbrukets första femtusen år 4000 f kr-1000 e kr*. 504 pp. Natur och kultur/LT i samarbete med Nordiska museet och Stift, Stockholm.

Widgren, M. 1983: *Settlement and farming systems in the early Iron Age: a study of fossil agrarian landscapes in Östergötland, Sweden*. Ph.D. thesis, Stockholm University, 132 pp.

Widgren, M. 1997: *Fossila landskap: en forskningsöversikt över odlingslandskapets utveckling från yngre bronsålder till tidig medeltid*. 91 pp. Kulturgeografiska Institutionen, Stockholms Universitet, Stockholm.

Widgren, M. 2012: Climate and causation in the Swedish Iron Age: learning from the present to understand the past. *Geografisk Tidsskrift-Danish Journal of Geography 112*, 126–134.

Widgren, M. & Pedersen, E. A. 2011: Agriculture in Sweden: 800 BC-AD 1000. *In* Myrdal, J. & Morell, M. (eds.): *The Agrarian History of Sweden: From 4000 BC to AD 2000*, 46–71. Nordic Academic Press, Lund.

Woods, D. 2010: Gildas and the Mystery Cloud of 536–7. *Journal of Theological Studies 61*, 226–234.

Xoplaki, E., Maheras, P. & Luterbacher, J. 2001: Variability of climate in meridional Balkans during the periods 1675–1715 and 1780–1830 and its impact on human life. *Climatic Change 48*, 581–615.

Zachrisson, T. 2017: The background of the odal rights: an archaeological discussion. *Danish Journal of Archaeology 6*, 118–132.

15023885, 0, Downloaded from https://onlinelibrary.wiley.com/doi/10.1111/bor.12672 by Statens Beredning, Wiley Online Library on [09/11/2024]. See the Terms and Conditions (https://onlinelibrary.wiley.com/terms-and-conditions) on Wiley Online Library for rules of use; OA articles are governed by the applicable Creative Commons License