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Understanding climate resilience in Scandinavia during the Neolithic and Early Bronze Age

Magdalena Maria Elisabeth Bunbury [a,b,*], Knut Ivar Austvoll [c], Erlend Kirkeng Jørgensen [d], Svein Vatsvåg Nielsen [e], Jutta Kneisel [a,f], Mara Weinelt [a,f]

[a] Cluster of Excellence, ROOTS – Social, Environmental, and Cultural Connectivity in Past Societies, Kiel University, Kiel, Germany
[b] ARC Centre of Excellence for Australian Biodiversity and Heritage, College of Arts, Society and Education, James Cook University, Cairns, Australia
[c] Department of Archaeology, Conservation, and History, University of Oslo, Oslo, Norway
[d] Norwegian Institute for Cultural Heritage Research, NIKU High North Department, Framsenteret, 9296, Tromsø, Norway
[e] Department of Archaeological Excavations and Natural Sciences, Museum of Archaeology, University of Stavanger, Norway
[f] Institute of Pre- and Protohistoric Archaeology, Kiel University, Kiel, Germany

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ABSTRACT

Mid and late-Holocene climate shifts are considered to have profoundly shaped demographic developments and adaptive responses of communities globally. Yet their onset, duration, and impact on Neolithic and Early Nordic Bronze Age communities in the high-latitude ranges of southern and north-western Scandinavia remain a major research gap. Here, we built on an emerging body of archaeological and paleoclimate data, encompassing 20,908 anthropogenic ^{14}C dates and 49 climate records from the Holocene. Additionally, we gathered and correlated a new archaeological dataset of 3649 houses from southern Scandinavia and southern Norway. In this study, we utilised 6268 reliable ^{14}C dates and 2519 dwellings to generate time series and socio-economic trends from ~4100 to 1100 BCE.

Our study revealed three key findings: (1) A distinct lateral zonation, with variations in the duration and timing of the Holocene Thermal Maximum (~7050–2050 BCE). In Southern Scandinavia, a warmer climate may have facilitated the spread of crop cultivation (*3820–3790* BCE), coinciding with significant population growth. Neolithic communities settled in permanent two-aisled houses 90–160 years later (*3700–3660* BCE). (2) The 2250 BCE (4.2 ka BP) cooling trend marked the beginning of a climate regime shift with varying duration and timing (~3450–1450 BCE). This period coincided with demographic growth, migration, crop cultivation diversity, and the development of houses with crop storage facilities (*2290–2215* BCE). (3) Severe abrupt cooling periods (~1850–1450 BCE) corresponded to short-term demographic decline including disruptions in trade networks with continental Europe. However, repopulation and redistribution of wealth (~1450 BCE), along with the development of stable three-aisled houses (*1475–1450* BCE), underscore the resilience of food-producing economies in mitigating environmental disturbances.

1. Introduction

Climate change has been recognised as a crucial factor shaping various aspects of human society, including socio-ecological changes, migration patterns, and even societal collapses (e.g., Cullen et al., 2000). Despite this recognition, understanding the relationships between climate change and human behaviour remains challenging due to complex and multifactorial causation, including variable climate trends and cultural developments across space and time. Moreover, analysis of such relationships requires long records of high-resolution environmental and multi-proxy cultural data (Jackson et al., 2017). The northern high-latitude regions of southern and north-western Scandinavia are excellent laboratories for studying human ecodynamics given the exceptionally large repertoire of archaeological and paleoclimate datasets across latitudinal ranges. Yet the onset and duration of key mid and late-Holocene climate shifts and their impacts on demographic trends and adaptive responses of Northern European communities remain a major research gap.

Specifically, two crucial climate regimes justify focused analysis: The mid-Holocene Thermal Maximum (HTM), when high latitude regions

* Corresponding author. Cluster of Excellence, ROOTS – Social, Environmental, and Cultural Connectivity in Past Societies, Kiel University, Kiel, Germany
E-mail address: magdalena.bunbury@jcu.edu.au (M.M.E. Bunbury).

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experience 5 °C warmer temperatures compared to preindustrial levels (Renssen et al., 2012), and the late-Holocene 2250 BCE (4.2 ka BP) climate shift. This shift refers to an interval of cooling and drying episodes in the North Atlantic through Europe to Asia (e.g., Kaniewski et al., 2018). Additionally, the Neolithic (N: ~4100/4000–1700 BCE) and Early Nordic Bronze Age (ENBA: ~1700–1100 BCE) exhibit important socio-ecological transformations. Key Neolithic changes encompass the spread of agricultural productivity, leading to population growth, and the establishment of permanent houses and hamlets (Bocquet-Appel and Bar Yosef, 2008). Noteworthy Bronze Age developments include the expansion of long-distance trade and the exchange of goods, which contribute to the accumulation of wealth and the emergence of economic hierarchies (Borgerhoff Mulder et al., 2009; Brink, 2013; Ling et al., 2018). Therefore, the primary aim of this study is to examine demographic dynamics across latitudinal ranges, encompassing population fluctuations, settlement reorganisation, and exchange networks, as well as economic transformations and adaptive responses, within the context of these transitional climate periods.

While climate dynamics are most intriguing when viewed from the perspective of sedentary, densely populated agricultural communities, the social aspects of human ecodynamics that determine the extent to which societies are likely to be affected by these changes vary based on different types of economic adaptations. Human ecodynamics encompasses the complex dynamics of stability, resilience, and transformation within socio-ecological relationships or systems (Fitzhugh et al., 2019). Resilience is the degree to which natural and human systems are susceptible to and able to cope with the effects of climate change and mitigate disturbances (Gallopín, 2006). For prehistoric communities, building resilience may involve implementing practices and technologies such as crop diversification and long-term crop storage to mitigate the impacts of short lengths of crop growing seasons in high-latitude ecosystems. The adaptive capacity of communities (people's ability to anticipate, respond to, and recover from the consequences of these changes) is the focus of this study.

The high latitude ranges of southern and north-western Scandinavia offer an opportunity for systematically exploring human ecodynamics across space and time given the diverse geophysical and ecological properties of the landscapes positioned between 50 and 70° North, including continental/terrestrial and oceanic environments. Indeed, southern Scandinavia (latitude ranges of 50–60°), southern Norway (latitude ranges of 60–65°N) and Arctic Norway (latitude ranges of 65–70°) encounter distinct extreme climate variability pending on topographies between high mountain ranges to coastal environments, cultural traditions, agricultural potential, and ecosystem instabilities. Specifically, the start and end of the cereal growing seasons can vary by up to several months from the southern to the northern parts of the region (Tveito et al., 2001). The dissimilarities in climate and growing seasons must have prompted distinct adaptations among the populations residing in different latitudinal regions.

The appearance and dispersal of farming in northern Europe happened around 1500 years later than their counterparts on the European plain, and this delay has been linked to the arrival of more stable climates in the region (Shennan et al., 2013). In northern Europe, the Holocene Thermal Maximum is characterised by a notable rise in summer temperatures, resulting in more productive terrestrial conditions and the rapid northward expansion of farming (Bonsall et al., 2002; Warden et al., 2017). Proxy reconstructions and model simulations suggest stable and warm climatic conditions (Renssen et al., 2012; Seppä et al., 2009). Nevertheless, there has been no systematic effort to examine the HTM across the study region; it has been broadly correlated with the beginning of the Neolithic period in southern Scandinavia (Warden et al., 2017).

The so-called 2250 BCE (4.2 ka BP) 'event' disrupted the HTM, marking the transition from the mid to late-Holocene epoch (Walker et al., 2014). This climate trend exerted a widespread and well-documented impact on human communities residing in tropical and subtropical areas, as evidenced by studies conducted on the Iberian Peninsula (Hinz et al., 2019; Schirrmacher et al., 2020; Weinelt et al., 2021), the Mediterranean (Jarriel, 2021), the Levant (Palmisano et al., 2021), and the Fertile Crescent (Lawrence et al., 2021). In the western and partially eastern Mediterranean region as well as the Levant, dry episodes are recorded for a longer period between 2350 and 1850 BCE (Bini et al., 2019; Cheng et al., 2015; Schirrmacher et al., 2020). Particularly in subtropical regions, which are characterised by fluctuations in monsoonal rainfall patterns (Railsback et al., 2018), populations endured severe drought episodes that challenged their economic and environmental capacities, compelling populations to migrate and abandon established settlements (e.g., Bini et al., 2019).

In northern Europe, the climate trend around 2250 BCE (4.2 ka BP) marks a shift toward colder and drier conditions associated with the onset of neoglaciation (Matthews, 2013). Declining summer temperatures and increasing winter temperatures, influenced by decreasing and increasing summer and winter insolation, respectively, plays a significant role in shaping long-term seasonal temperature fluctuations (e.g. Longo et al., 2020). In the Skagerrak Sea, located between Denmark and Norway, there is evidence of a long-term decrease in winter and deep-water temperatures spanning from 2350 to 1550 BCE covering the Late Neolithic and Early Nordic Bronze Age (Butruille et al., 2017). However, the onset, duration, and spatial extent of this cooling trend within our study region still lack certainty. Moreover, its potential impacts on human ecodynamics in the northern high-latitude regions remain elusive (e.g., Bakka and Kaland, 1971; Haughton, 2023; Prøsch-Danielsen et al., 2018).

Southern Scandinavia, southern Norway, and Arctic Norway also exhibit variations in cultural traditions throughout different time periods. For example, the adoption of an agro-pastoral economy and permanence of place happenes in southern Scandinavia in the Early Neolithic (EN I: ~4100/4000–3500 BCE) and in southern Norway in the Late Neolithic (LN I: ~2350–1950 BCE) (Nielsen et al., 2019; Sørensen, 2014). In Arctic Norway, this tradition remains a patchy presence, and longhouses only appear after the transition to the Bronze Age, with distinct evidence suggesting longhouse constructions from 1300/1200 BCE (Arntzen, 2012). However, the transition to an agro-pastoral economy and the development of distinct and permanent Neolithic and Bronze Age house architecture have only provided broad age ranges (e.g., Gron and Sørensen, 2018; Nielsen, 2019). Additionally, there is a clear need to understand the differences in demographic and adaptive developments at both supra-regional (trends encompassing the entire study region) and regional scales (trends encompassing our three regions).

In this study, we address the following question: How did the HTM and 2250 BCE (4.2 ka BP) climate shifts influence socio-ecological dynamics at supra-regional and regional scales in southern and north-western Scandinavia, and what, if any, are their impacts on population fluctuations, settlement reorganisation, interaction networks and economic transformations?

Demographic reconstructions currently rely heavily on Summed Probability Distributions (SPDs) of ^{14}C dates to approximate human population trends over extended temporal scales (Shennan et al., 2013). For a thorough comprehension of the method and its inherent biases, Appendix A offers a comprehensive exposition. One notable advantage of this approach is its ability to facilitate a direct comparison between demographic and climate trends, both on a supra-regional and regional scale (e.g., Palmisano et al., 2021).

However, previous SPD analyses carried out within our study region have been subject to certain limitations (Hinz et al., 2012; Jørgensen, 2020; Nielsen et al., 2019; Solheim and Persson, 2018). These studies have often lacked independent proxies for assessing population and settlement trends, such as large-scale assessments on house frequencies and sizes (Palmisano et al., 2017; Stoddart et al., 2019 for demographic reconstructions in Italy).

To fill in the existing research gaps, we compiled a comprehensive multidisciplinary dataset, which includes 20,908 anthropogenic radiocarbon (^{14}C) dates and 49 climate profiles spanning the Holocene. We developed a comprehensive data quality assessment and regard 6268 Neolithic (N) and Early Nordic Bronze Age (ENBA) dates as reliable (Appendices A-C). Additionally, we collated archaeological information from the grey literature, resulting in a new compilation of 3649 houses (including 2519 dwellings from N and ENBA from 1458 archaeological sites) (Appendices D–E). This house dataset significantly contributes to our understanding of archaeological settlement data and human ecodynamics in the study region.

By employing various statistical approaches such as current Frequency (summing and aoristic) and Bayesian methods (outlier models), we enhance the chronological control of long-term and short-term socio-ecological dynamics, equivalent to a few generations (e.g., Bunbury et al., 2022) (Appendices A, F-G). By shedding new light on crucial aspects of human ecodynamics relating to changes in subsistence strategies and architectural innovations, our findings contribute to a better understanding of demographic and adaptive responses of the northern latitude Neolithic and Bronze Age communities, particularly in the face of climate uncertainties.

2. Geography and demography of southern and north-western scandinavia

Our study area covers southern and north-western Scandinavia, which consists of modern-day countries and surrounding islands of

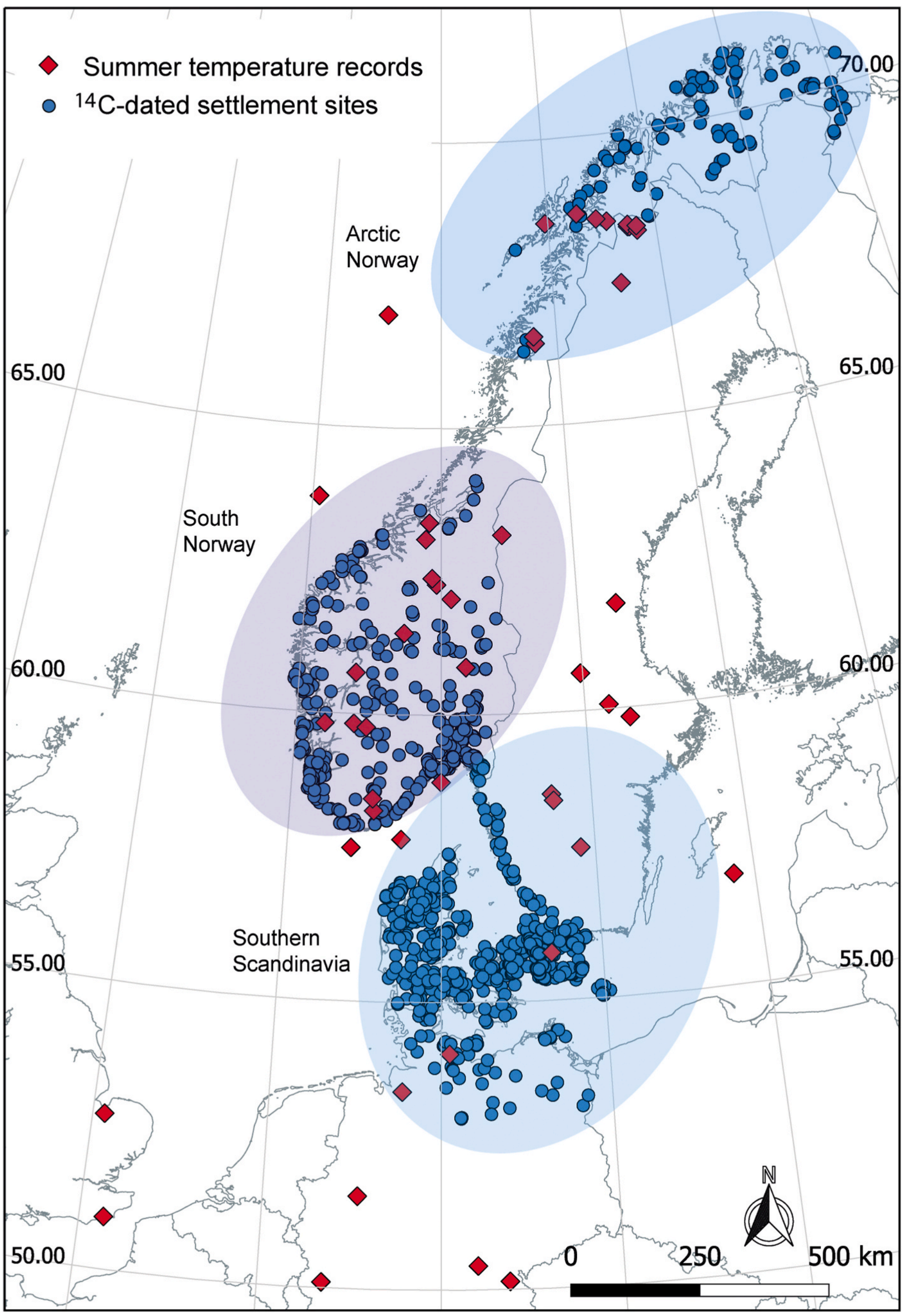


Fig. 1. Radiocarbon-dated settlement sites and summer temperature records across southern Scandinavia, southern Norway and Arctic Norway. The map displays a total of 1734 settlement sites with a corresponding 6268 reliable ^{14}C dates (Appendices A–C**)**. Summer temperature records are based on marine, lacustrine, bog and speleothem records (cf., Table A1).

Denmark, Norway, south-western coast of Sweden, and the northern German plain (Schleswig-Holstein and Mecklenburg-Vorpommern) (Fig. 1). We specifically focus on three climatologically and culturally distinct regions, namely southern Scandinavia, southern Norway (up to Trøndelag county, or central Norway), and Arctic Norway, i.e. from northern Trøndelag to Troms og Finnmark county.

Southern Scandinavia encompasses a diverse landscape, encompassing mountainous areas, lakes, and moraines in southern Sweden, low-lying areas of archipelagos and islands in southern Sweden, and the Danish Isles. Jutland and Schleswig-Holstein in northern Germany are characterised by a moraine landscape, which is divided into sandy Geest and flat fertile marshes. Southern Scandinavia has warm summers and mild winters with high concentrations of arable land for cereal cultivation, especially in the moraine landscapes (Sørensen, 2014).

Southern Norway is divided into a western and an eastern region, with high valleys and mountain plateaus in between. The Skagerrak coast in eastern Norway connects the landscape with western Sweden, while some of the most fertile areas with sandy and well-drained soils are around the Oslo Fjord region. Particularly fertile areas for farmland are in the southern region and central Norway. Currently, Norway has the lowest population density in Europe after Iceland, with settlements and urban structures concentrated in the coastal zones under the influence of the Norwegian coastal current, which transports heat northward, providing exceptionally mild climates in high-latitude Europe, especially in western Norway. The Atlantic meridional overturning circulation, drives a strong influx of warm water all along the Norwegian coastline, regulating local climates and producing Atlantic conditions into high-Arctic latitude, with ice-free waters year-round and relatively strong terrestrial productivity compared to other circumpolar areas of similar latitude. This results in the remarkable potential for agriculture even into the Arctic Circle.

2.1. Southern Scandinavia

The dispersal of farming in southern Scandinavia is associated with the Funnel-Beaker culture (~4100–2800 BCE, Table 1), which originated in northern Germany and spread as far as southern Norway and the Mälaren Valley north of Stockholm in Sweden (Sørensen et al., 2021). The Funnel-Beaker settlements are situated in areas within the hinterlands, enabling a transition from the marine-dominated diet, previously consumed by foraging societies, to a terrestrial diet (Nielsen et al., 2019). Sheep/goats (*Ovis/Capra*) spread around 4100 BCE in northern Germany, followed by cattle (*Bos* sp.), and pigs (*Sus* sp.) (Sørensen, 2014). After ~4000 BCE, Neolithic communities also introduced founder crops such as emmer (*Triticum diconum*), einkorn (*Triticum monococcum*), bread wheat (*Triticum aestivum/compactum*), spelt (*Triticum spelta*), and naked barley (*Hordeum vulgare/nudum*) (Sørensen et al., 2021).

Table 1
The chronology of the Neolithic and Early Nordic Bronze Age in southern and north-western Scandinavia.

Period	Abbreviation	Cal BCE	Culture
Early Neolithic Ia	EN Ia	~4100/ 4000–3800	Funnel Beaker Culture
Early Neolithic Ib	EN Ib	~3800–3500	
Early Neolithic II	EN II	~3500–3300	
Middle Neolithic A	MN A	~3300–2800	
Middle Neolithic B	MN B	~2800–2350/ 2300	Single Grave/Battle Axe Culture
Late Neolithic I	LN I	~2350/ 2300–1950	Bell Beaker Culture
Late Neolithic II	LN II	~1950–1750/ 1700	Únětice imports
Early Nordic Bronze Age Ia	ENBA Ia	~1750/ 1700–1650	
Early Nordic Bronze Age Ib	ENBA Ib	~1650–1500	
Early Nordic Bronze Age II	ENBA II	~1500–1300	
Early Nordic Bronze Age III	ENBA III	~1300–1100	

The arrival of Neolithic settlers, coupled with the adoption of an agro-pastoral economy and increased availability of a broader range of food sources, initiates a population boom around 4100–3500 BCE, as shown by previous SPD studies (Feeser et al., 2016; Hinz et al., 2012). Around 4000 BCE, small and scattered settlements were replaced by permanent post-supported two-aisled longhouses for single families, which are part of an north-western European building tradition (Nielsen, 2019). Scholars hypothesise that the rapid diffusion of crops and two-aisled houses occurred simultaneously in southern Scandinavia and reached a hegemonic status around 3700 BCE (Gron and Sørensen, 2018; Nielsen, 2021; Sørensen et al., 2021).

During the Middle Neolithic (MN: Table 1), previously published SPDs show a decline in population around 3350–3100 BCE (Hinz et al., 2012). Between approximately 2900 and 2600 BCE, permanent settlements also exhibit a decline in northern Germany, Denmark, and southeast Norway (Nielsen, 2019; Nielsen et al., 2019; Iversen, 2015). It has been argued that the absence of well-dated house structures may be attributed to a process of 'de-Neolithisation' in southern Norway (Hinsch, 1955; Nielsen et al., 2019), a more mobile and nomadic society (Andersson, 2004; Larsson, 1992; Nielsen et al., 2019), or agglomerated settlements with fewer but larger houses (Hinz et al., 2012). The Funnel-Beaker culture in southern Scandinavia ended during the Store Valby phase at ~2900–2800 BCE (Iversen, 2020), giving rise to a period of cultural heterogeneity that included the Pitted Ware culture and Corded Ware groups, such as the Single Grave Culture on Jutland and the Battle Axe Culture in Norway and Sweden (Brozio et al., 2019; Iversen, 2015).

The Late Neolithic (LN, Table 1) is characterised by significant changes in population sizes, settlement patterns, and economies (Kristiansen, 2010). These transformations have been associated with the spread of the Bell Beaker Culture, which is believed to have its origins in the Iberian Peninsula around 2600 BCE (Pena, 2014), This culture exerted a significant influence in the Limfjord region of Denmark after 2350 BCE (Sarauw, 2007). The Bell Beaker Culture utilised local flint resources to produce substantial amounts of flint daggers and engaged in extensive long-distance dagger and metal exchange with the Únětice culture of central Europe (Apel, 2001). In northern Germany, increasing land opening and the dominance of intensive agricultural strategies are associated with high deposition rates of status symbols in the form of flint daggers and metal objects (Brozio et al., 2019).

The Early Nordic Bronze Age (ENBA, Table 1) is characterised by significant changes in material culture, particularly the production of locally made metal artifacts (Vandkilde, 2014). Demographic decline has been noted from 1650 to 1500 BCE (ENBA Ib) on southern Jutland and in north-eastern Germany (Kneisel et al., 2019). The rise of the ENBA in Denmark and Germany has been associated with the disappearance of the Únětice culture in Eastern Central Europe around 1600/1500 BCE, leading to disruptions in the south-eastern exchange networks and opening them for access to the northern region, to e.g. metal resources (Kneisel, 2012; Kneisel et al., 2019, 2022).

The characteristic material culture of the ENBA is primarily associated with the period 1500–1100 BCE (ENBA II–III, Table 1). During this time, monumental burial mounds, such as earthen mounds or cairns, often containing rich bronze objects, were constructed in various parts of Scandinavia (Holst et al., 2001; Skoglund, 2005). Previously published SPDs have shown an increase in population in southern Jutland and north-eastern Germany during this period, more precisely 1450–1300 BCE (Feeser et al., 2019). Settlements were then organised into larger and smaller longhouses and economic buildings (Artursson, 2015; Meier, 2013). Hamlets or villages so far are not known yet. Northern Europe transformed into a hierarchical society, characterised by the construction of barrows and rich grave goods, and the replacement of two-aisled houses with considerably larger three-aisled houses around 1500 BCE, particularly in regions like Denmark, southern Sweden, and the Netherlands (Donat, 2018; Kneisel et al., 2019). This society persisted for approximately 400 years, with houses starting to decrease in size around 1300 BCE (Kristiansen, 2006) and leading to a more egalitarian structure in grave construction around 1100 BC.

2.2. Southern Norway

The Early Neolithic of southern Norway is recognised by a traditional hunter-fisher lifestyle, although objects, such as polished flint axes and ceramics did make their way into the region, most likely as exotic goods. Forest clearance is documented in pollen archives already during the Mesolithic but more pronounced after c. 3800 BCE; however, a direct connection to agricultural activities has not been established (Høgestøl and Prøsch-Danielsen, 2006). Similarly, the Middle Neolithic is highly enigmatic, with some even calling it a 'black-box phase' (Prescott and Glørstad, 2015). While there is evidence of small-scale crop cultivation and husbandry among some forager groups during the MN A (Nielsen et al., 2023), traces of the distinct Battle Axe Culture during the MN B are present in eastern Norway while some axes also spread westward as well, though the cultural traits become less certain along the south and western coast of Norway (Bertelsen, 2005).

After 2300 BCE, subsistence intensification towards agro-pastoralism is observed, evident in large deforestation patterns, the emergence of heathland, and the discovery of cereal grains in settlement contexts. The 'late arrival' of farming in southern Norway is highlighted by osteological remains indicative of animal husbandry and other evidence from well-preserved sites, such as rock shelters (Hjelle et al., 2016; Hufthammer, 2015; Prescott, 2020; Prøsch-Danielsen and Simonsen, 2000). Moreover, material culture and technological know-how, including hundreds of flint daggers and early practice in metallurgy, spread through open-sea crossings over the Skagerrak strait (Prescott and Glørstad, 2015; Prescott et al., 2018; Østmo, 2005). Contemporarily, two-aisled longhouses emerged, possibly indicating a population boom or at least a drastic demographic changeover.

Overseas crossings continued into the ENBA I, evident through the introduction of the earliest metal objects to local communities, including swords, axes and spears (Engedal, 2010). By the ENBA II, southern Norway was drawn into a fully-fledged Bronze Age system with a similar material assembly as that of southern Scandinavia, including monumental burial mounds, three-aisled longhouses and a rich assembly of metal objects made in a Nordic metalwork style (Austvoll, 2019).

2.3. Arctic Norway

Arctic Norway reflects a different adaptation to what is known from the Neolithic complexes on the European continent, or the Nordic Bronze Age of southern Scandinavia. Anything reminiscent of Neolithic or Bronze Age material culture (houses, domesticates, farming, Neolithic flint axes or metallurgy, etc) is limited to patchy settlements along the western Arctic coast of Norway, with diminishing densities and longevity towards the north (Arntzen, 2013). The northern limit of this distribution of material culture of the Nordic Bronze Age complex (including longhouse settlements) is currently at 69° north, outside of Tromsø (Arntzen, 2015; Arntzen and Sommerseth, 2010). However, the investigative efforts and data coverage for this period are particularly low throughout Arctic Norway (Johansen, 1979; Johansen and Vorren, 1986).

Arctic Norway stands out as a fascinating region characterised by a diverse array of adaptive strategies, featuring continuous foraging populations and small-scale food production experiments, coupled with marine harvesting practices. Migrants originating from the southern regions potentially introduce these practices (Jørgensen et al., 2023; Pääkkönen et al., 2018). Throughout the ages, foraging remains the primary economic activity in the area, persisting into the modern era. Specifically, the period 5050–2250 BCE is characterised by a proliferation of various technological advancements, artistic expressions, and diverse settlement patterns. Most striking is the trend towards increased site investments through the emergence of house clusters on regularly revisited sites, on coastal headlands, promontories, and archipelagos of strategic economic and logistical locations (Damm et al., 2020). This suggests increased investment in particular places and likely reflects seasonal, semi-sedentary communities (Damm et al., 2020).

From 5000 BCE, rock art appeared in large quantities in the region, containing rich scenes of a hunter-gatherer cosmology, depicting both terrestrial and marine fauna and hunting scenes, as well as social events (Gjerde, 2010). Simultaneously, new technologies were introduced to the region, with Early Northern Comb Ware ceramics, bifacial projectile points and a ground slate industry. While this early, foraging pottery is limited to the Russian border zone, the lithic technologies diffuse across the area, with slate technology becoming the dominant lithic industry for millennia (Jørgensen, 2021). These organisational and technological innovations slightly predate a major population boom centred on 4000 BCE, as reconstructed from ^{14}C-based paleodemographic modelling and supported by site counts and frequency of semi-subterranean dwelling features per habitation phase of individual sites (Jørgensen and Riede, 2019; Vollan, 2022). Around 2250 BCE, larger houses appear across the landscape alongside a second population boom (Jørgensen and Riede, 2019). Previous research as pointed to a sharp demographic downturn around 1550 BCE (Jørgensen, 2020), evidenced by increased mobility, the break-up of previous large-scale settlements, a turn to small houses and impermanent structures, alongside greater use of inland areas and after 1450 BCE including reindeer hunting pits (Damm et al., 2020; Jørgensen and Riede, 2019). Concurrently, a new wave of pottery was introduced, in the form of asbestos-tempered ware, from present-day Northern Finland and NW Russia (Jørgensen et al., 2023).

3. Materials and methods: climate, radiocarbon, and settlement datasets and approaches

3.1. Regional climate compilations

State-of-the-art compilations of Holocene climate reconstructions were presented utilising regional climate records. These paleoclimatological compilations focused on high-resolution records of summer temperatures from various archives across southern and north-western Scandinavia integrating terrestrial lacustrine and peat, and marine records based on a variety of different proxy reconstructions into robust regional time series. Specifically, data were obtained from regional and global data compilations (e.g., Kaufman et al., 2020).

We assembled a total of 49 climate records from 49 sites, including marine, lacustrine, bog and speleothem archives (Table A1). They cover an area of 50°–70°N and from 0° to 20°E. Individual records were z-scored to enable a better comparison of different proxy reconstructions (Kaufman et al., 2020). Z-scored records were stacked within 5°*5° grids spanning the last 12,000 years. It is important to note that there were much fewer data available for winter as compared to summer temperatures. As most proxies used for quantitative temperature reconstruction rely on biomarker remains of biota that predominantly thrive during warm seasons, calibrations for winter conditions in high-latitude environments are generally considered less reliable.

3.2. Radiocarbon data compilations and quality assessments

We accumulated 20,908 previously published ^{14}C ages from 3914 archaeological sites across southern and north-western Scandinavia spanning the Holocene. Data collection procedures were elaborated in Appendix A, and the dataset is available in Appendix B. Our dataset adds significantly to the body of population proxy data for our region compared to recent studies (Bird et al., 2022). We applied a data quality assessment using the most parsimonious exclusions of ^{14}C ages in chronological models to maximise sample numbers. We have developed a sophisticated system for outlier analysis, which is comprehensively explained in Appendices A-B. We categorised outliers into four classes depending on their degree of reliability (Bunbury et al., 2022; Schmid et al., 2019), which were summarised in Table A2. Overall, a subset of 6268 reliable ^{14}C dates was retained spanning the uncalibrated age range between 5500 and 2600 ka BP (Fig. 1, Appendix C). Of these, 4017 dates are from southern Scandinavia, 1674 from southern Norway, and 577 from Arctic Norway. We also highlighted ^{14}C ages from animal husbandry and crops to assess the introduction of an agro-pastoral economy in southern Scandinavia.

3.3. House data compilations

The core of this study was a new settlement dataset, which covered modern-day regions of Denmark (including the island of Bornholm), Scania, southern Norway and the northern German plain (Appendix A). The lead author extracted data for Denmark from 1564 excavation reports, with detailed descriptions in Appendices A and D-E. Altogether, we collated data from 3649 houses from 1603 archaeological sites (Appendix D; Table A4). We considered 2519 houses from 1458 sites as Neolithic and ENBA dwellings (e.g., not economic buildings). This data collection was biased with a high quantity of houses in southern Scandinavia (n = 2390, 1396 sites) and low quantities in southern Norway (n = 129, 62 sites) (Fig. 2). Dwellings were provided with additional information about their area size (n = 1400), length or width (n = 282), type of aisle (n = 1565), orientation (n = 989), two-aisled houses (n = 581), three-aisled houses (n = 287), hybrid houses (n = 19), and houses with sunken floors (n = 67).

3.4. Summed probability distributions (SPDs) as a proxy of population size

Past human population trends were modelled using *Summed Probability Distributions* (SPDs) of ^{14}C dates (Crema, 2022; Rick, 1987; Shennan et al., 2013). The method itself and its limitations were discussed in Appendix A. To validate their robustness, scholars have urged to corroborate SPDs with archaeological trends, such as the frequency of houses and sizes (Palmisano et al., 2017; Stoddart et al., 2019). Furthermore, it has been suggested to use a minimum of 200 ^{14}C dates spanning 750–14,000 years to improve SPD accuracy (Bunbury et al., 2022; Williams, 2012). We applied both recommendations in this study. We generated several quantitative analyses of SPDs using the *rcarbon* package v.1.5.1 (Crema and Bevan, 2021), an extension package for *R* (Team, 2019). Terrestrial samples were calibrated using the IntCal20 calibration curve for the Northern Hemisphere (Reimer et al., 2020). To distinguish our estimates from earlier studies, all modelled population boom and bust periods were indicated in italics, used a '~' symbol, and are listed in Table A3.

We minimised biases in SPD plots by (1) merging and supplementing existing databases and screening data for quality (Schmid et al., 2019); (2) using ^{14}C dates directly associated with human settlement activities; (3) presenting smoothed and unnormalised ^{14}C distributions of summed ^{14}C dates to avoid artificial peaks in the SPDs at points where the ^{14}C calibration curve is steep (Fig. A1a; Weninger et al., 2015); (4) aggregating the median value of calibrated ^{14}C dates within 100-year bins to

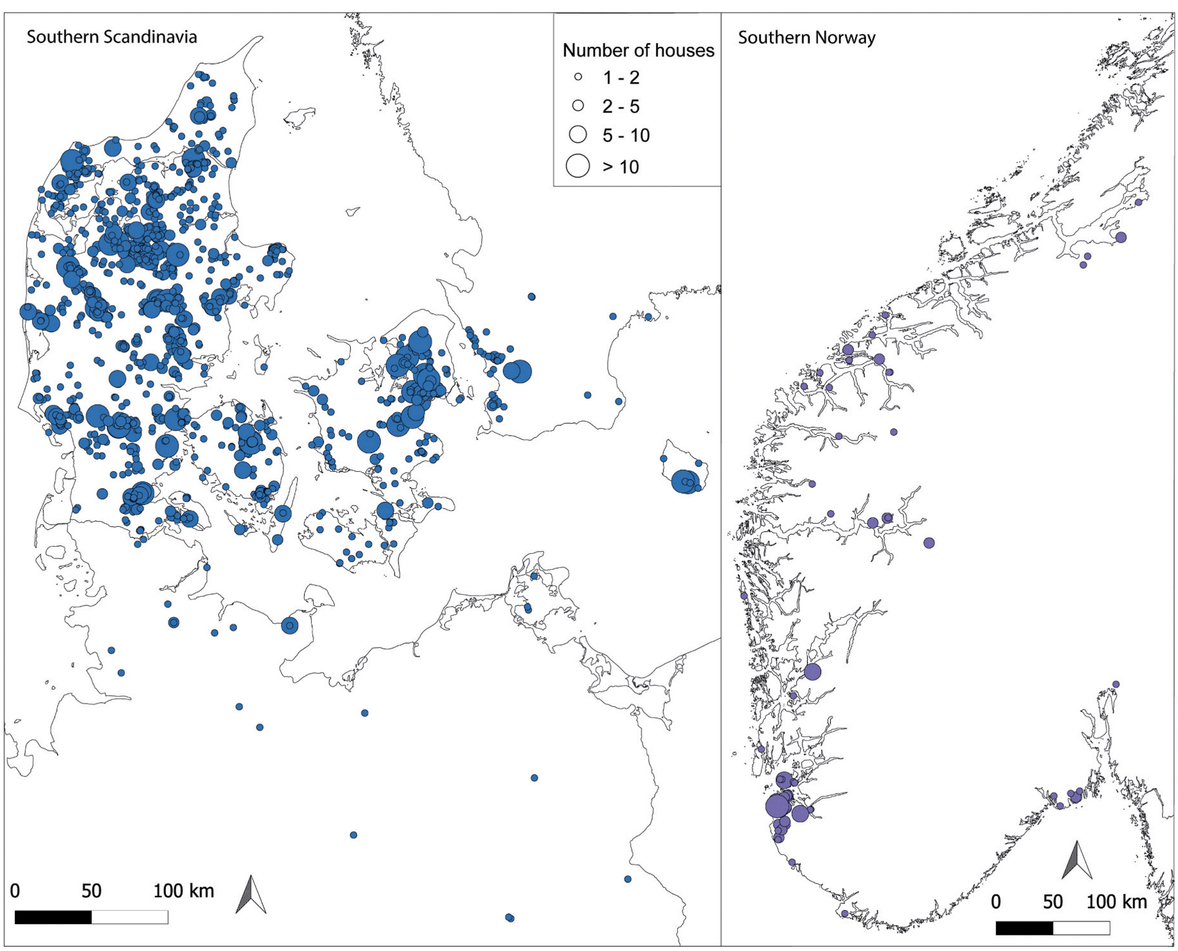


Fig. 2. The distribution of 2519 reliable Neolithic and Early Nordic Bronze Age houses from 1458 archaeological sites within southern Scandinavia and southern Norway. Large quantities of houses are on the Jutland peninsula, the Danish Isles and in south-western Norway.

avoid oversampling archaeological contexts (Crema and Bevan, 2021); (5) testing against theoretical growth models to identify specific local divergence in population growth based on an expected exponential population growth scenario (Shennan et al., 2013; Timpson et al., 2014); (6) assessing spatial variation in population growth rates of aggregated ^{14}C dates (based on calibrated dates, bins, and site locations) in 100-year intervals to avoid pre-established regional, cultural, and climate classifications (Crema et al., 2017); and (7) comparing SPD plots with settlement data using the aoristic statistical method, which quantifies the frequency, sizes, and orientation of dwellings of different chronological precision (typologically and ^{14}C-dated) into 100-year intervals (see Johnson, 2004 for a detailed explanation of the method). We provided detailed information on all approaches in Appendix A, and the code used and written in R statistical computing language to reproduce the data in Appendix F.

3.5. Bayesian highest probability distributions to model socio-economic events

The onset of socio-economic events was based on the *Highest Probability Distributions* (HPDs) of multiple ^{14}C dates in a Bayesian framework (Bronk Ramsey, 2009). The accuracy and precision of the HPDs depend on the distribution of the data (e.g., the contexts of the ^{14}C dates) and the data itself (e.g., the likelihood of the sample being an outlier) (Schmid, 2018). We described the method in detail in Appendix A. We modelled HPDs of archaeological events using the Oxcal v 4.4 platform (Bronk Ramsey, 2020). We used the program 'OxCalparser' to build robust Bayesian Outlier models in OxCal while ensuring data entry accuracy (Schmid et al., 2018). All modelled HPD intervals were indicated in italics and presented in Table A5, both at 68% and 95% probabilities. Unless stated otherwise, results discussed within this paper were based on the 68% probability. We constructed Bayesian models based on 'top-down' approaches to represent human activities by evaluating ^{14}C ages as a single entity using uniform single-phase models for unordered groups (Bunbury et al., 2022).

We minimised bias in HPD plots by (1) using reliable ^{14}C dates from known contexts related to agricultural activities and dwellings; (2) using at least eight ^{14}C dates for the event in question to maximise the accuracy and precision of Bayesian models (Schmid et al., 2019); (3) using different Outlier models depending on the material types (Bunbury et al., 2022); (4) calculating the probability distributions for the difference between two parameters (Table A6). We ran each model multiple times, and modelled ages were rounded to the nearest five years to avoid spurious precision. We provide all the Bayesian codes used in the paper in Appendix G.

4. Results: climate and demographic trends

The analysis of both quantitative (SPDs and aoristic weights) and qualitative (HPDs) data revealed a variety of concurrent changes in demographic and environmental variables, along with some less apparent trajectories. Multiple indicators related to population fluctuations, settlement patterns, and economic transformations showed boom periods during the EN Ib, LN I–II, and ENBA II, with significant points of convergence on supra-regional and regional scales. Notably, a bust period was observed during ENBA Ib. It is important to acknowledge that not all trends showed linear development. For example, despite the onset of a climate regime shift and a long-term cooling trend beginning at the start of the LN I, there was an exponential increase in both houses and population.

4.1. Regional climate trends

Over the past 12,000 years, paleoclimate compilations showed a well-defined HTM with different regional zonation and time-lags across latitudinal bands (Fig. 3). Generally, long-term summer cooling trends were observed across the study area from about 6050 BCE onwards, with an evident earlier start around 7050 BCE.

Furthermore, summer temperature reconstructions showed a clear 6250 BCE (8.2 ka BP) event, followed by the onset of the HTM in all stacked records except for the northernmost latitudinal band between 65 and 70°N (Fig. 3A). While not as prominent as the 6250 BCE (8.2 ka BP) event, we identified the beginning of a climate regime shift, which has previously been referred to as the 2250 BCE (4.2 ka BP) 'event' in tropical and subtropical regions. This climate regime shift marks (i) the first cooler century after the 6250 BCE (8.2 ka BP) event, (ii) a relatively abrupt end of the HTM, and (iii) the onset of cooler conditions in the northern regions. While long-term summer cooling trends were observed across the study area, long-term warming of winter temperatures was only evident in the southern latitudinal band between 50 and 55°N (Fig. 3D).

Overall, stacked records of latitudinal bands showed clear regional variations in terms of the timing, duration, and intensity of the HTM. The northernmost stack (65–70°N, 5–20°E, Fig. 3A) suggested an early and prolonged HTM between 7050 and 2050 BCE in Arctic Norway. This distinct warming step was however preceded by a moderate gradual warming starting at 8050 BCE. In addition to a prominent 6250 BCE (8.2 ka BP) event and a moderate climate, regime shift around 2050 BCE, this stack features a significant cooling period following the HTM, extending from ~1850 to 1650 BCE.

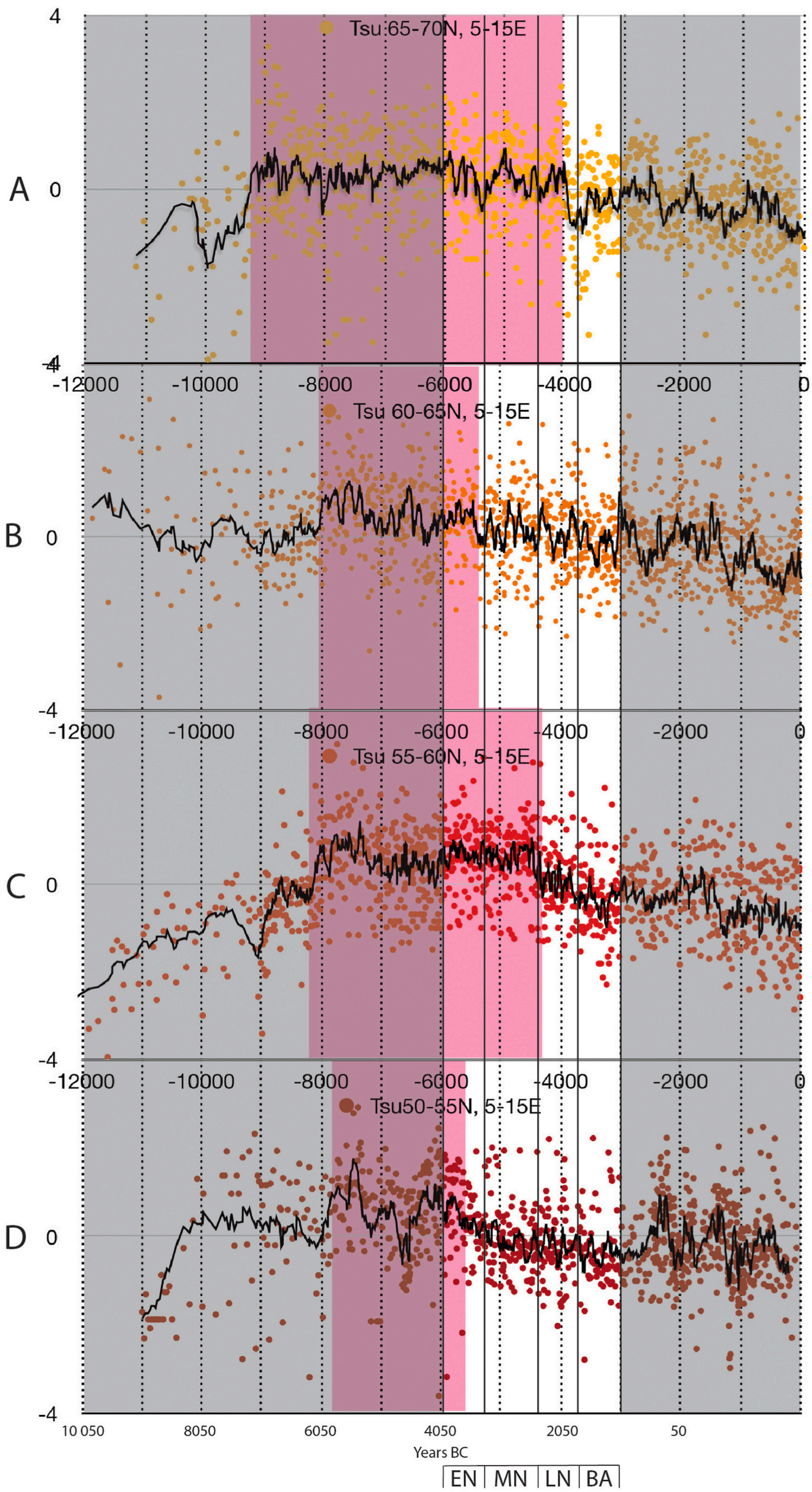
In Southern Norway (60–65°N, 5–15°E, Fig. 3B) the HTM plateau started at 6050 BCE, also here preceded by moderate warming after 7050 BCE, but did not manifest a clearly defined termination. This stack also exhibited a long-term cooling trend that encompasses the entire Late Holocene. However, from around 3450 BCE onwards, the variation in the frequency and amplitude of cooling and warming events increased.

In southern Scandinavia (southern Norway and Jutland) (55–60°N, 5–20°E, Fig. 3C), a notable and stable HTM persisted between 6150 and 2550 BCE. Its onset occurred in two-steps, with the first one starting at 7050 BCE. After 6050 BCE, the region underwent a gradual 1300-year cooling period that reached its lowest value around 1250 BCE. Other superimposed cooling trends occurred from 2350, 2050 and 1650 BCE.

In contrast to the northern latitudes, the stacked records from southern Scandinavia (the northern German plain and southern Denmark, 50–55°N, 5–15°E, Fig. 3D) suggested a moderate warming as early as 8050 BCE, followed by a further warming step at 6050 BCE. Two prominent mid-Holocene cooling periods peaking around 5250 BCE and 4550 BCE, as well as an earlier termination of the HTM (around 4350/3650 BCE). The onset of a long-term cooling trend occurred between 3650 and 650 BCE. This early temperature decline may be a result of overlaying effects of rapidly intensifying land use activities, which biased the pollen-based temperature reconstructions towards temperature underestimates (e.g., Marcott et al., 2013). The general cooling patterns after the HTM were superimposed by a sequence of prominent cooling events around 2550, 2050, 1650, and 1450 BCE. Notably a marked shift to high-amplitude temperature variability of centennial scale frequency here occurred subsequent to 550 BCE and is recorded only in this latitudinal band.

4.2. Supra-regional demographic trends

Fig. 4A displayes the SPD summarising data from southern and north-western Scandinavia. The null model (represented by the grey area) suggested three major population boom periods. The first population peak occurred during EN Ib (~3700 BCE), during the LN II period (~2000 BCE) and ENBA II (~1400–1300 BCE). Trends showed the lowest bust at the transition between the ENBA Ib–II (~1500 BCE). The model observed a significant deviation of the SPD from the expected theoretical exponential population growth trend ($p = 0.001$). Significant growth occurred during EN Ib (~*3815–3610* BCE), followed by two minor bust periods during MN A and B (~*2940–2865* and ~*2545–2340*



(caption on next page)

Fig. 3. Summer temperature records spanning the last 12,000 years across four latitudinal bands. Symbols mark data points of individual summer temperature records as assembled for four latitudinal bands (cf., **Table A1**). The lines are 10 pt running means of the stacked records. The pink boxes mark Holocene Thermal Maximum (HTM) of different regional zonation and time-lags, identified by a distinct initial rapid temperature increase, and ending with a sharp temperature decrease at the same time marking the onset of both higher frequency and amplitude temperature variability. **A.** 65–70° N, northern Norway, including the western coastal regions; **B.** 60–65° N, southern Norway; **C.** 55–60° N, southern Scandinavia, specifically southern Norway and Jutland; **D.** 50–55° N, southern Scandinavia, specifically southern Denmark and the northern German plain.

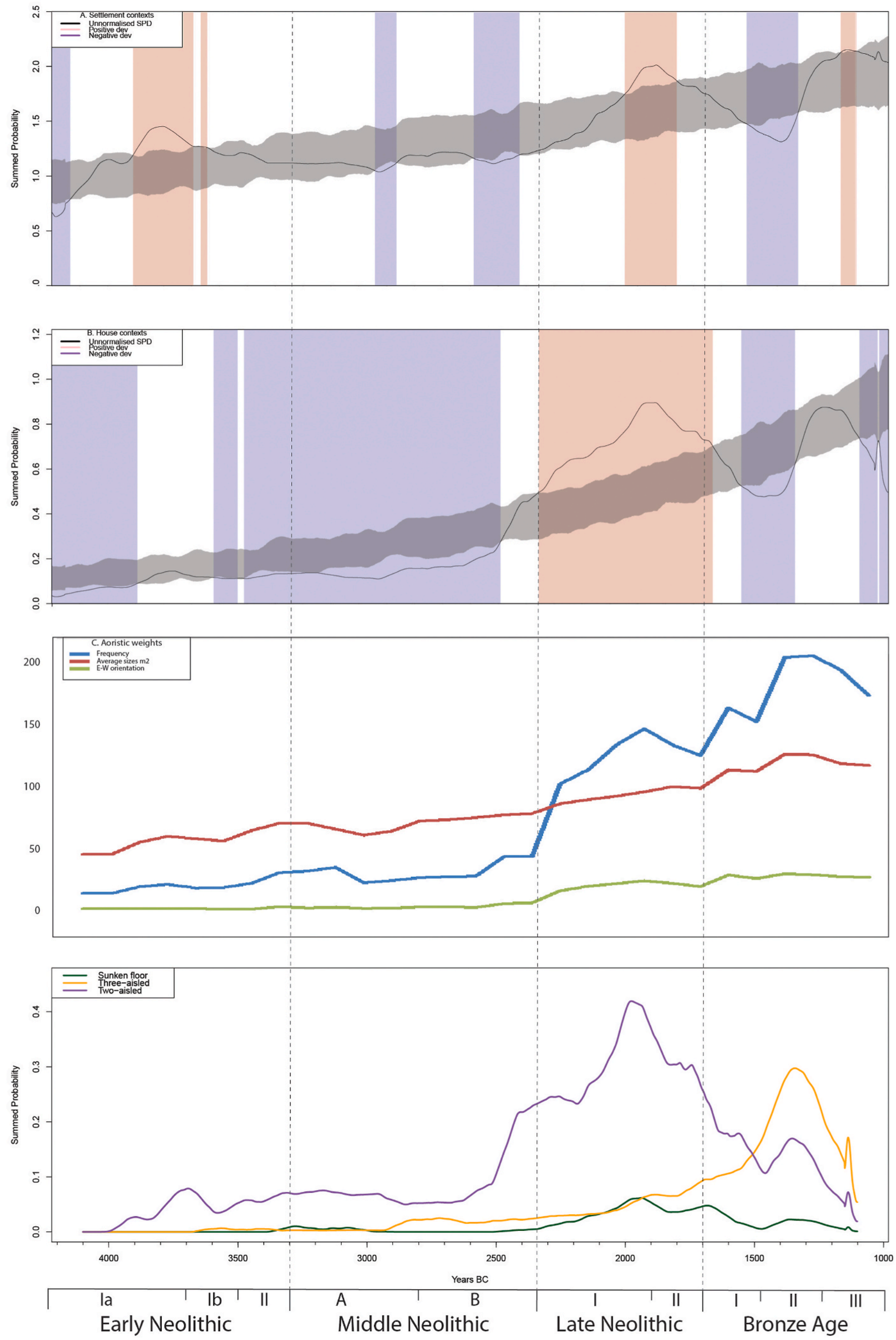


Fig. 4. Comparison of demographic time-series on supra-regional sales (4100–1100 BCE). A-B. Smoothed and unnormalised SPDs, exponential fit. **A.** 6268 reliable ^{14}C dates from settlement contexts. **B.** 1684 reliable ^{14}C dates from dwelling contexts. **C.** Aoristic analyses of Neolithic and Eearly Nordic Bronze Age houses summarising their frequency (n = 2519, blue line), average sizes (n = 1369, red line) and E-W orientation (n = 385, green line). **D.** Stacked SPDs of reliable ^{14}C dates from two-aisled (n = 518, purple line), three-aisled houses (n = 254, orange line), and Danish houses with sunken floors (n = 67, green line).

BCE). Another period of significant growth occurred at the LN I–II transition (~*2050–1860* BCE), followed by a major bust at the ENBA Ib–II transition (~*1610–1420* BCE).

Fig. 4B shows the SPD of ^{14}C dates reliably obtained from house contexts from southern Scandinavia and southern Norway (cf., Fig. 2). The SPD pattern mirrored that of Fig. 4A; for instance, dwellings experienced a significant increase during LN I–II (~*2385–1730* BCE). There was, however, one notable exception: there was no discernible increase in house numbers during the EN. Significant negative deviations were observed before 3790 BCE, suggesting that permanent houses were likely developed after this period, but keeping in mind that this could be an edge-effect if the model. This trend was further compared to the SPD of ^{14}C dates from crops, as shown in the supplementary data (cf., Fig. A1c). There was an increase in the utilisation during EN Ib (~*3795-3585* BCE) and LN (~*2075-1735* BCE); and a decrease during MN and the ENBA Ib-II.

Fig. 4C presents aoristic weights of house frequencies, sizes, and orientations from southern Scandinavia and southern Norway. The data revealed that the frequency of typologically and ^{14}C-dated houses increased over time with exponential growth during LN I, ENBA Ia and II. During MN A, LN II, ENBA Ib and III, there were also brief periods of regression. These boom-and-bust trends mirrored the SPDs using ^{14}C dates from dwelling contexts (Fig. 4B), showing the robustness of SPD plots when considering the contexts of ^{14}C dates. There was, however, one significant exemption. During the MN A period (~3300–3000 BCE), the frequency of houses increased, which diverged from the results solely obtained from ^{14}C dating, which might have suggested a disparity in the sampling intensities of ^{14}C dates during the MN period. This observation was reinforced by the limited quantity of cereal grains that were dated from the MN period, resulting in a reduced number of ^{14}C dates generated for this specific period (cf., Figs. A1c, A6).

The analysis of house sizes revealed a consistent linear growth, indicating an overall increase in the size of houses over time. Minor regression phases coincided with declines in house frequencies. During the LN II and ENBA II periods, there was a significant increase in house sizes, with some houses reaching 300–350 m^2 during LN II and 436-496 m^2 during ENBA II (cf., Fig. A7). From the LN I period onwards, the prevailing and most distinctive orientation of houses in both southern Scandinavia and southern Norway is east–west (cf., Fig. A8).

Fig. 4D compares the SPDs of three house types in southern Scandinavia and southern Norway. During EN Ib–ENBA I (~3700–1500 BCE), and specifically during MN B–LN II (~2500–1700 BCE), two-aisled houses were the dominant house type matching the boom period of houses observed in Fig. 4B. Sunken houses were mainly prevalent between LN I–II (~2300–1600 BCE), with some exceptions during the Single Grave Culture and ENBA II periods. Three-aisled longhouses occurred from approximately 2900 BCE, with their highest peak during ENBA II (~1500–1300 BCE), when the occurrence of two-aisled longhouses experienced a significant reduction within the region (cf., Fig. A3).

Fig. 5 presents Bayesian HPDs of significant socio-economic trends. These trends showed that early Neolithic farmers introduced domesticates between *3990* and *3955* BCE. During EN Ia, they introduced sheep/goats (*Ovis/Capra* at *4310–4100* BCE) and cattle (*Bos* sp. at *4000–3955* BCE), while during EN Ib they introduced pigs (*Sus* sp. at *3820–3660* BCE) and a variety of 'founder crops' between *3820* and *3790* BCE, apart from *Hordeum vulgare* which may have been introduced at *3455–3195* BCE. Furthermore, farmers established permanent single-family post-supported two-aisled houses at *3700–3660* BCE. During LN I, a new local Danish house style with sunken floors was developed between *2290* and *2215* BCE. Hybrid houses, a combination of two-aisled and three-aisled dwellings, were built during LN II from *1910* to

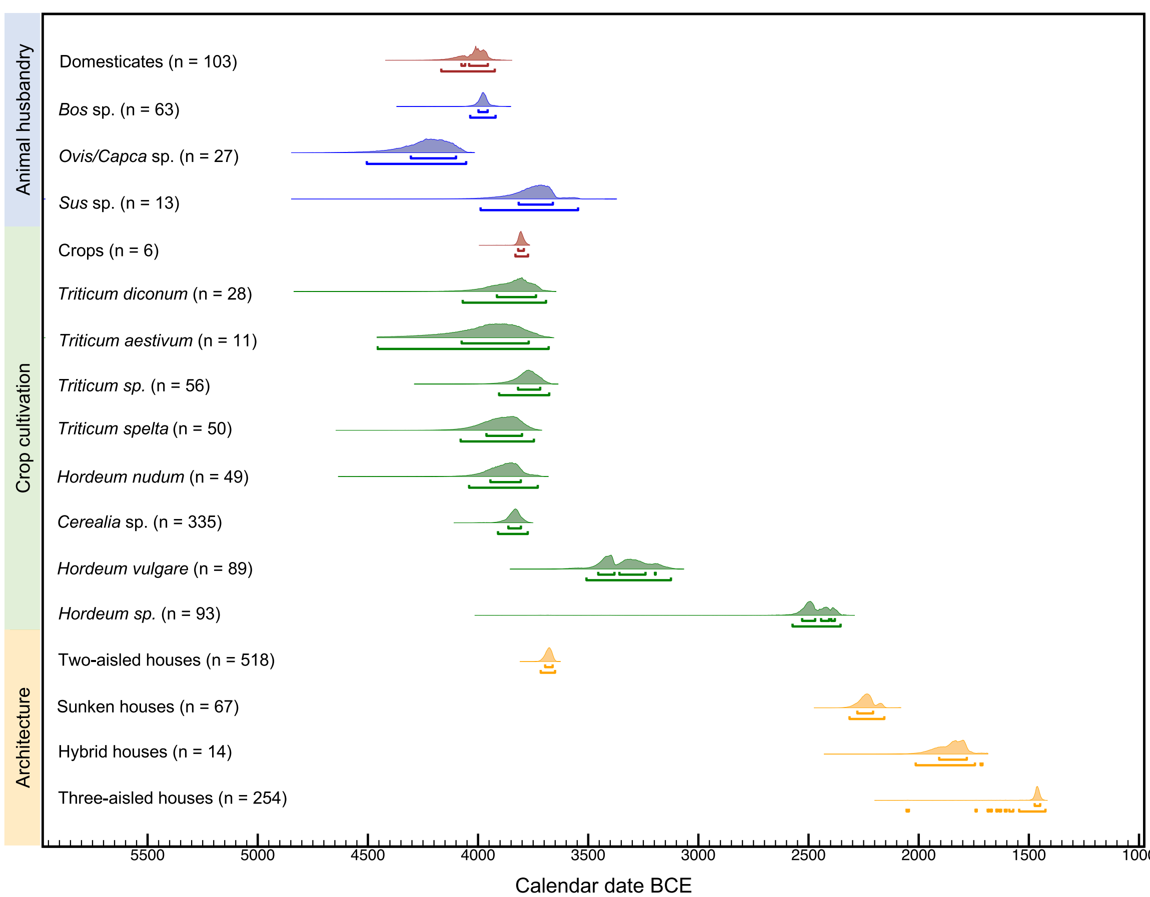


Fig. 5. *Highest Probability Distributions* (HPDs) of an argo-pastoral economy and house types. Significant HPDs include: The spread of animal husbandry (*3990–3955* BCE); crops (*3820–3790* BCE); two-aisled houses (*3700–3660* BCE); houses with sunken floors (*2290–2215* BC); hybrid houses (*1910–1780* BCE), and three-aisled houses (*1475–1450* BCE). HPDs are presented at both 68% and 95% probabilities (cf., **Table A5**).

1780 BCE, while three-aisled houses were *1475–1450* BCE at 68% probability and *2060–1425* BCE at 95% probability. These house trends align well with SPDs of house types as shown in Fig. 4D.

4.3. Regional and local demographic trends

Fig. 6 displays the SPD of an exponential population growth model summarising data from our three regions. For southern Scandinavia, the population growth aligned with the supra-regional trend, given that 70% of the ^{14}C dates derived from this region. One clear exemption was a more pronounced bust period in the Early Bronze Age (ENBA I–II), followed by a boom during the ENBA III. In southern Norway, two distinct population boom periods were visible. The first one occurred briefly during EN I, and the second one during the late LN I and into the LN II. Very different from southern Scandinavia, there was a bust period during the transition from MN B to the LN I. These findings are consistent with earlier assessments made by Nielsen et al. (2019), although, in our model the peak during EN I is slightly less pronounced, while the duration of the subsequent bust period is longer. In Arctic Norway, there were no notable positive local deviations in the population growth pattern, which indicated a robust exponential population growth through time. This is also signalled by a high global p-value (0.5954), supporting the hypothesis of exponential growth simulated by the model. However, one significant trough period was identified at

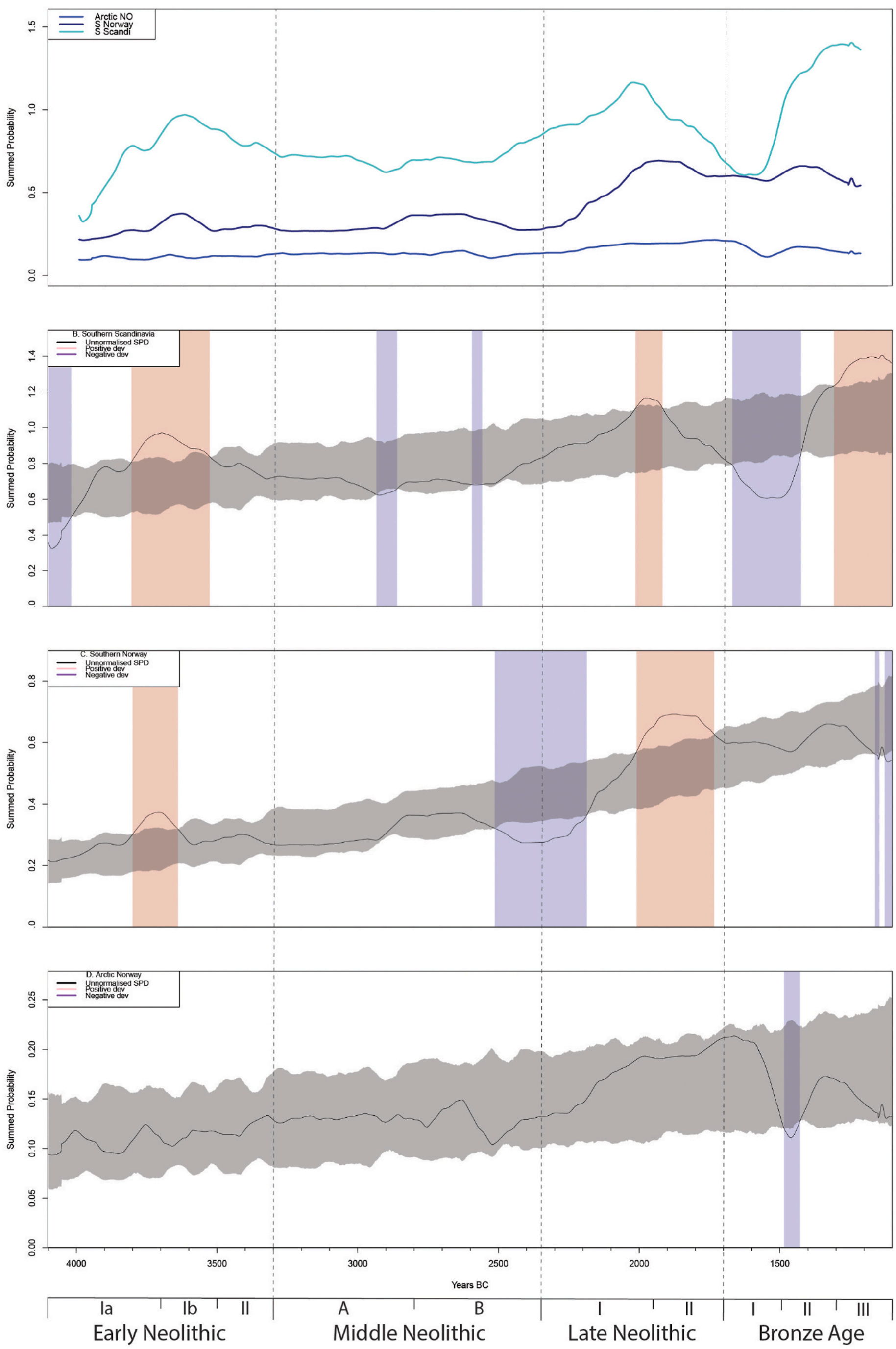


Fig. 6. Comparison of demographic time-series from southern Scandinavia, southern Norway and Arctic Norway (4100–1100 BCE). A. Stacked SPDs of southern Scandinavia (n = 4296, dark blue line); southern Norway (n = 1279, turquoise line); and Arctic Norway (n = 577, blue line). **B-D**. Exponential fit of smoothed and unnormalised SPDs for each region.

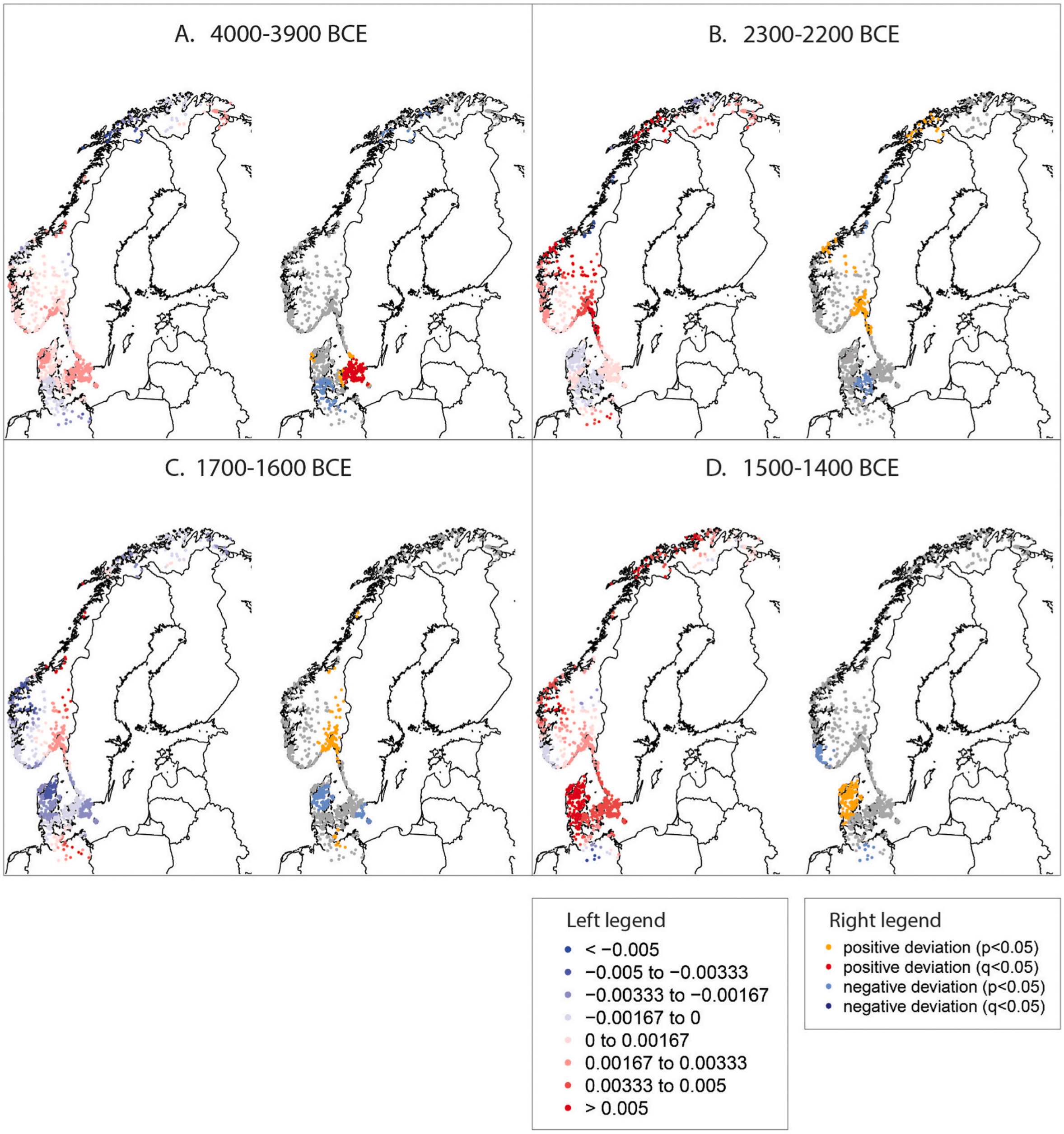


Fig. 7. Four significant transitions of spatial population growth rates and permutation tests across southern and north-western Scandinavia. The left figure of each transition shows local geometric growth rates. The right figure shows areas where growth is significantly higher or lower than the null model (the supra-regional trend). Significance is highlighted in terms of q-values (red and dark blue dots) and p-values (yellow and light blue dots). All 29 transitions are portrayed in Figs. A4-A5 in Appendix A.

~*1485–1430* BCE, which coincided with the same time frame of collapse observed in southern Scandinavia, if not shorter in duration. These findings align with earlier assessments made by Jørgensen and Riede (2019), who identified a trough at around 1550 BCE.

Figures A4-5 in Appendix A show a sequence of 29 transitions. An increase in growth rates was observed for transitions 3 (3900-3800 BCE), 12 (3000-2900 BCE), 19–21 (2300-2000 BCE), and 27 (1500-1400 BCE), which are consistent with the observed pattern of exponential population growth (Fig. 4B). Our results suggested that there was significant spatial heterogeneity in growth rates in southern Scandinavia, southern Norway and Arctic Norway, despite the variability of sample sizes of ^{14}C dates in each area. The EN Ia phase showed positive growth rates across the study area; however, higher-than-expected growth rates were only recorded for Zealand and southern Scania (Fig. 7A). Indeed, the lack of significant results in growth rates elsewhere may be attributed to two plausible explanations. First, it is unlikely that growth rates remained linear across the entire study region, as populations tend to exhibit diverse growth patterns in different geographical areas. Second, there might have been variations in growth rates in these regions, but the sample size of available data was too small to detect statistically significant deviations, as indicated in Figs. 4 and 6B.

The EN Ib phase demonstrated minor growth in Jutland, northern Germany, and Arctic Norway. The EN II phase recorded growth in western Norway and Jutland, while the MN A phase showed growth in Zealand. These population trends suggested a reflection of the expansion of the Funnel Beaker Culture in southern Scandinavia. In western Norway, these trends were unrelated to agriculture and instead reflected the continuation of the traditional hunter-fisher lifestyle (Nielsen et al., 2019). In Arctic Norway, boom periods before the Pre-Roman Iron Age peak at 200 BCE reflected endemic hunter-gatherer population fluctuations and increasing seasonal sedentism (Jørgensen and Riede, 2019).

The MN B phase showed minor population growth in south-eastern Norway, Jutland and the eastern Danish isles, representing the Single Grave Culture and Battle Axe Culture. Western and Arctic Norway did not exhibit significant population boom or bust periods, suggesting that population growth followed the same trend as the null model. The LN I phase demonstrated spatial unevenness, with notable population growth in southern and Arctic Norway during 2200–2000 BCE (Fig. 7B), followed by population growth in northern Jutland around 2100 BCE, and significant decline on the Danish isles. This pattern corresponded possibly to the Bell Beaker spread to north Jutland in Denmark, the spread of farming in southern Norway around 2350 BC, and the development of large houses in communal clusters and associated midden accumulation as part of the so-called 'Gressbakken'-phase in east Arctic Norway around the same time (Jørgensen and Riede, 2019).

The LN II period showed population growth in southern Norway, southern Jutland, and eastern Sweden, indicating intensified exchange networks between southern Sweden and the Únětice culture in central Europe (Vandkilde, 2017). The ENBA I showed spatial heterogeneity, where the population grew in northern Germany, south-east Sweden, the Danish isles and Arctic Norway; while there was a significant decline in population around 1600 BCE on the Danish isles and northern Jutland (Fig. 7C). In contrast, the ENBA II exhibited spatial population growth throughout the entire region, while significant growth was specifically observed for southern Scandinavia, marking the emergence of a distinctive Nordic Bronze Age society (Fig. 7D). The ENBA III demonstrated an increase in population on the Danish isles and Scania, and a decrease across the Jutland peninsula. While this paper does not delve into the detailed causes of these local-scale patterns, they should serve as a foundation for future research endeavours.

5. Discussion: understanding Neolithic and Early Nordic Bronze Age ecodynamics

In this paper, we systematically evaluated two key climate shifts and demographic trends in different latitudinal ranges in southern and north-western Scandinavia. Our focus was on regional developments in southern Scandinavia, southern Norway and Arctic Norway. Lastly, we presented a more precise chronological model of economic transformations and settlement reorganisation that complements the use of SPD plots. Subsequently, we aimed to examine how climate shifts affected human ecodynamics concerning both the dispersal of Neolithic communities within southern Scandinavia and Late Neolithic and Early Nordic Bronze Age developments across the study region.

We tested certain fundamental assumptions. If coinciding abrupt cultural and environmental changes occurred, there was a potential linkage between the two domains (Kintigh and Ingram, 2018). For example, if there was a bust phase in population that paralleled or occurred after a climate shift within a reasonable response time, it was a potential response to this event, although accidental coincidence cannot be ruled out. In contrast, climate shifts that occurred during human boom phases suggest higher resilience and ability to handle climate changes. Additionally, innovative power, as reflected in new advances (such as architectural innovation or new subsistence strategies), lent supporting evidence for the high adaptation capability of communities.

5.1. The HTM and the spread of farming within southern Scandinavia

Scholars have linked the arrival of more stable climates, which cumulated in the HTM, with the adaptation of farming in northern Europe (Glykou, 2016; Krause-Kyora et al., 2013; Warden et al., 2017). Warmer temperatures and longer growing seasons provided a conducive environment for the cultivation of crops in high-latitude environments. Here, we assessed whether the spread of farming were a direct response to the warming trend of the HTM.

Climate shifts: Based on a compilation of summer temperature reconstructions, our results demonstrated a clear latitudinal zonation of the HTM with off-set duration and timing. Specifically, the HTM started in Arctic Norway around 7050 BCE, in southern Scandinavia around 6150 BCE, and in southern Norway around 6050 BCE. These results align well with Risebrobakken et al. (2011), who identified an early HTM in the eastern Nordic Seas between ~7050 and 4050 BCE. On the contrary, Warden et al. (2017) suggested a much later and rapid onset of the HTM in the Baltic Sea in ~4050 BCE, however, their assessed records start much later at ~5130 BCE and are based on a single marine site, and are not supported by nearby terrestrial records.

Population trends: During EN I, significant population growth occurred in southern Scandinavia and southern Norway. These population growth rates align with those in the British Isles at 3850 BCE (Bevan et al., 2017), around 4050 BCE for continental Europe (Shennan et al., 2013), ~4000–3350 BCE for southern Scandinavia (Hinz et al., 2012), ~4050 BCE for Arctic Norway (Jørgensen, 2020), ~4000 BCE for western Norway (Bergsvik et al., 2021), as well as ~4050–3550 BCE for eastern Fennoscandia and the Baltic region (Tallavaara and Seppä, 2012; Warden et al., 2017). We would like to point out that earlier models use different contexts of ^{14}C dates, such as from burials, or they include varied materials. Interestingly, our modelled timing of population growth overlapped with important economic and cultural changes in southern Scandinavia, such as the widespread use of food crops and permanent two-aisled houses.

Economic transformations: Our revised analysis of ^{14}C dates suggested that Neolithic communities introduced animal husbandry during EN Ia in southern Scandinavia, while a more widespread distribution of food crops occurred during EN Ib. Our revised modelled age ranges for the onset of an agro-pastoral economy align with earlier paleoenvironmental and archaeological proxies (e.g., Gron and Sørensen, 2018; Sørensen, 2013). For example, pollen cores show the presence of ribwort plantain starting 4100 BCE (*Plantago lanceolata*), a plant associated with pastures (Kirleis and Fischer, 2014; Kirleis et al., 2012). Additionally, evidence of soil degradation resulting from agricultural practices appeared already around 4000 BC in the region (Gron and Sørensen, 2018).

Settlement reorganisation: Here we generated the first robust estimate for the onset of two-aisled houses in southern Scandinavia (HPD of *3700–3660* BCE); which in our dataset happened 90–160 years after the widespread distribution of crops (HPD of *3820–3790* BCE; SPD of ~*3795-3585* BCE). This finding deviates from previous estimates that broadly posited the onset of such houses during the EN Ia period (Andersson et al., 2016; Donat, 2018; Nielsen, 2019). Specifically, two-aisled seasonal houses with rounded gables and an inner row of roof-supporting posts, known as the Mosby house type in Scania, north-east Germany, and Zealand, have been broadly dated to the EN I–MNA I periods (Madsen, 2019). However, the early ^{14}C dates obtained from archaeological sites featuring Mosby-style houses present certain limitations. In some cases, these dates lack clear stratification and do not originate from the actual house itself, as exemplified by the *locus classicus* Mosby site (Appendix D). Alternatively, certain ^{14}C dates associated with the Mosby house in Kærup N, Zealand, yielded anomalous Iron Age results. Although re-dating Mosby-type houses could provide valuable insights in chronological assessments, our Bayesian modelling of 518 ^{14}C dates supported the establishment of two-aisled houses during EN Ib.

While the HTM facilitated these important demographic developments, we demonstrated a certain time lag between the onset of the HTM (6150–6050 BCE) and the appearance of Neolithic communities in southern Scandinavia (after ~4000 BCE). Additionally, the adaptation of farming practices had not yet reached southern and Arctic Norway. This suggests that multiple factors, including the HTM, availability of arable land, and growing population pressure from central Europe, likely influenced the spread of farming practices (cf., Sørensen and Karg, 2014). The delay in the spread of agriculture to latitudinal ranges above

60°N could be attributed to the smaller population size in those areas. With a smaller population, the impetus for agricultural expansion might have been less urgent. Additionally, the distances between different regions within northern Europe could have posed challenges to the spread of agricultural practices. The diffusion of knowledge and technology related to farming might have been slower in areas that were more remote or isolated.

While our current methods could not accurately quantify the appearance of Neolithic communities in southern Scandinavia, we argue that it may have been driven by small groups of farmers due to the absence of Neolithic communities in southern and Arctic Norway and the limited ^{14}C dates of crops and animal husbandry during EN Ia. The large-scale dispersal of Neolithic communities occurred during EN Ib, as evidenced by the widespread distribution of food crops and permanent two-aisled houses that coincided with significant population growth. Our findings suggested that the Neolithic dispersal extended over 300 years, occurring approximately 4000–3700 BCE.

Middle Neolithic developments: Our extensive collection of houses provided compelling evidence of uninterrupted habitation throughout the MN period. We revealed a minor decline in the frequency of houses and crops during the EN II and MN B periods as determined by SPDs and aoristic weights. These periods of reduced activity occurred similarly to earlier population estimates, for instance around 3500 BCE in continental Europe (Shennan et al., 2013) and 3350–3100 BCE in southern Scandinavia (Hinz et al., 2012). Typologically dated houses, on the contrary, showed a small increase in house frequencies and sizes between 3300 and 3100 BCE. We demonstrated that the exclusion of typologically dated houses would result in a biased representation of the distribution of houses (cf., Fig. A6). This bias arose because houses from the LN and ENBA periods, which often include grain storage facilities, are commonly dated using ^{14}C dating techniques based on grains found within their contexts (cf. Fig. A1c).

The general decline in the number of houses during the MN period is associated with changes in architecture and subsistence practices, as well as the decline of the Funnel Beaker culture around the transition the MN A to the MN B. The MN period witnessed the appearance of Pitted Ware Culture groups in many regions of southern Scandinavia, which exhibited a subsistence based on hunting and gathering combined with farming and husbandry, and the Single Grave and Battle Axe groups, which are associated with pastoralism. While the Corded Ware groups are primarily identified through their burial practices, these cultural transitions during the MN period led to increased mobility, changes in group sizes, and a reduced necessity for larger houses. In south-eastern Norway, for instance, there are very few traces of buildings from this period, while in western Norway where a forager economy persisted, circular pit houses have been documented at many coastal sites (Nielsen et al., 2019).

5.2. The 2250 BCE (4.2 ka BP) climate regime shift and Late Neolithic and Early Nordic Bronze Age developments

Our objective was to investigate the direct influence of the 2250 BCE (4.2 ka BP) cooling period on the ecodynamics of the LN and ENBA at different latitudinal ranges.

Climate shift: We suggested that the 2250 BCE (4.2 ka BP) cooling period was not a transient occurrence, but instead marked the onset of a climate regime shift of different off-set timing and duration. Specifically, this prolonged cooling period started early in southern Scandinavia (55–60°N) at 3650 BCE and in southern Norway at 3450 BCE. At 2550 BCE, a gradual cooling trend occurred in southern Scandinavia (50–55°N), while around 2050 BCE Arctic Norway had a moderate climate regime shift and a much later, but significant cooling period at 1850–1650 BCE.

These results align well with earlier research, which, in a novel approach to reconstruct winter temperatures, identified a long-term decrease in winter and deep-water temperatures between 2350 and 1550 BCE in the Skagerrak region, suggesting a predominantly negative phase of the North Atlantic Oscillation (Butruille et al., 2017). Regional paleoenvironmental records showed various lengths of climate deterioration. For instance, the Lake Bliden cores in Denmark indicate a wetter period between 2350 and 2100 BCE (Olsen et al., 2010), while the Sellevollmyra bog in Arctic Norway documents lower temperatures and two wet periods at 2300–1860 BCE and 1660–1630 BCE (Vorren et al., 2007). We argue that our stacked climate records provided a more robust coherent picture of climate variability in latitudinal ranges by emphasising the regional rather than highly variable local patterns.

Supra-regional to local population trends: On a local scale, the Jutland peninsula experienced a temporary decline in population growth during the same period when the population was on the rise in southern Norway. These results suggested a spatial variation in population dynamics at 2350 BCE that may be linked to the localised climatic conditions and environmental factors at 55–60°N, as well as demographic processes involving the spread of farming in southern Norway.

At the regional scale, trends showed significant population growth in southern Scandinavia and southern Norway from the late LN I and into the LN II (**Fig. 7B**). Earlier demographic models show similar boom periods at 2050 BCE in Arctic Norway (Jørgensen, 2020) and 2050–1790 BCE in southern Norway (Nielsen et al., 2019), while southern Jutland and north-eastern Germany have demonstrated a somewhat earlier timeframe (2200-2100 BCE: Feeser et al., 2019). In our Fig. 6B, we can however observe a change in population growth in southern Scandinavia around 2600 BCE, which led to the significant deviation during the LN. In comparison, the corresponding shift in southern Norway took place around the MN–LN transition, i.e. 2350 BCE.

The ENBA I and II illustrated a significant population bust period in southern Scandinavia and Arctic Norway, and subsequent population growth across the study region at ~1500–1300 BCE. The significant demographic growth marks, as argued above, the emergence of a distinctive Nordic Bronze Age society (Schäfer Di-Maida, 2023).

5.2.1. Southern Scandinavia

Economic transformations: We showed that crops intensified at settlement sites in southern Scandinavia and southern Norway during LN (cf., Fig. A1c). Although our assessment did not distinguish between different crop types, earlier archaeobotanical studies in Jutland demonstrate a notable shift towards more diverse agriculture during the LN and ENBA periods (Andreasen, 2009). Late Neolithic communities cultivated both wheat and barley, while Early Nordic Bronze Age communities cultivated multiple cereal crops, such as naked and hulled barley and several types of wheat and spelt, simultaneously at most sites (Andreasen, 2009).

The long-term diversification of agriculture starting after ~2300 BCE was a direct response to the gradual cooling trend that started about two centuries earlier affecting regions between 50 and 55°N, and the superimposed cooling trend at 2350 BCE impacting regions between 55 and 60°N. Regions between 50 and 60°N have typically been more favourable for agriculture than those between 60 and 70°N. It has been argued that communities cultivated multiple crops at settlement sites to mitigate the potential impact of environmental uncertainties, particularly the risk of crop failure and to ensure food security and dietary diversity (Marston, 2011). Additionally, the intensification of hulled barley and spelt may have functioned as an adaptive strategy towards the long-term cooling period, while the re-introduction of naked barley after 2300 BCE reflects an increase in manuring intensities, enhancing crop productivity in areas with limited resources (Brozio et al., 2019; Kanstrup et al., 2014). Overall, the long-term and systematic agricultural diversification and intensification, in combination with an increase in manuring reflects a more developed agricultural subsistence economy among these communities.

Settlement reorganisation: In this study, we significantly improved the precision of the onset of houses with sunken floors, hybrid, and three-aisled houses. These houses played a crucial role in comprehending the sustained existence of settlement sites, the advancement of sedentary lifestyles, and the extended storage of crops (Brink, 2013; Sarauw, 2006; Simonsen, 2017).

Houses with sunken floors: We provided the initial Bayesian estimate for the onset of houses with sunken floors at *2290–2215* BCE. Earlier research broadly dated early developments of such houses in Skjelborg, central Jutland, typologically to the Single Grave Culture spanning the MN B and LN I periods (Hübner, 2005). While these typological assessments may be accurate, we showed that ^{14}C dates obtained from cereal grains within the sunken floor areas confidently dated three houses to the LN I period (Diverhøj, Glattrup VI-West, Mannehøjgård IV), 17 houses to the LN II period (Birkholmvej, Glattrup VI-West), and nine houses to the NBA I–III periods (Gilmosevej, Hestehaven, Kongehøj II) (Appendix D).

Houses with sunken floors become prominent in the Limfjord region on northern Jutland and other regions of Jutland and eastern Scania and have been associated with the Bell Beaker culture (Vandkilde and Nicolis, 2001). The sunken floor areas are indicative of constant clearing of the floors (Simonsen, 2017). The presence of sickles, quernstones, furrows left by ploughing with an ard and charred cereal grains in such houses serves as evidence for the extended periods of habitation and increased agricultural activities during the LN II (Dollar, 2013; Sarauw, 2006; Simonsen, 2017). Furthermore, sunken floor houses provide insulation from the ground, creating a barrier that helps keep grains cool and dry. This insulation is particularly beneficial during colder seasons and periods of lower agricultural productivity, as it contributes to the preservation and storage of grains (Sørensen, 2014). Although we cannot definitively attribute the development of sunken floor houses to cooling periods, their occurrence during the LN period may have been influenced by climatic changes.

Hybrid houses: We dated the onset of hybrid houses during LN II (HPD of *1910–1780* BCE); earlier studies broadly place them at the transition of the ENBA I–II (Ethelberg, 2000). We would like to point out that the dataset of ^{14}C-dated hybrid houses is small when compared to other types of houses, and the start HPD could shift if more ^{14}C dates become available. Hybrid houses emerged both on Jutland and southern Norway; they are a combination of two-aisled houses with sunken floors and three-aisled house forms (Borup, 2018).

Three-aisled longhouses: Our Bayesian model presented the first robust estimate of the onset of three-aisled longhouses in southern Scandinavia and southern Norway, dated to the beginning of the ENBA II at *1475–1450* BCE (HPD at 68% probability), thus replacing two-aisled longhouses (cf., Fig. A3) . Earlier research broadly suggests their emergence around 1500 BCE (Nielsen, 2019), except in Mecklenburg-western Pomerania, where the tradition of three-aisled houses has never been adopted (Schmidt, 2013). Nevertheless, it has been speculated that three-aisled houses are already constructed during the LN and ENBA I (Nielsen, 2019). While our model confirmed this assumption (HPD of *2060–1425* BCE at 95% probability), it is not certain whether early and small three-aisled houses functioned as outhouses instead of dwellings, which needs further assessment.

The development of three-aisled houses has been driven by changes in social organisation and increasing social complexity (Kristiansen, 2010). The larger size and more elaborate internal divisions may reflect the emergence of a stratified society with hierarchical structures (Ethelberg et al., 2000). They can serve as symbols of status and wealth, signalling the social standing of their inhabitants. The increasing size provides space for crop storage, and communal activities, and allows for the integration of livestock within the dwelling. These factors can be advantageous in coping with both the challenges posed by the changing climate and the need for increased agricultural production.

Exchange networks and wealth: Our analysis demonstrated that the sizes of houses significantly increased during the LN and ENBA, with short regression phases around 1800–1700 and 1600–1500 BCE. We speculated that house size fluctuations might have been linked with the expansion and contraction of exchange networks, due to the availability of resources and wealth, which, in turn, can influence the size of houses.

Around 2050 BCE, local flint production in the Limfjord area in Jutland increased and the Únětice culture from central Europe emerged, which facilitates wealth through exchange networks across Europe (Apel, 2001; Kneisel, 2012; Vandkilde, 2017). The introduction of newfound wealth through these exchange networks led to the construction of significantly larger houses compared to earlier Neolithic periods. Our data revealed that the sizes of house varied within the range 30–350 m^{2}(cf., **Fig. A7**). The differentiation in sizes may portray an increased social stratification and economic inequality, due to resource competition starting during the long-term cooling period (e.g., Artursson, 2009; Borgerhoff Mulder et al., 2009).

We speculated that the decline in house frequencies and wealth during the ENBA Ia (~1600 BCE) can be attributed, at least in part, to the collapse of exchange networks with Únětice cultural groups. This collapse coincides with new sources of metal production in northwestern Germany and Jutland in the south (Kneisel, 2012). During ENBA II, exchange networks flourish again (Vandkilde, 2014), coinciding with the end of the long-term cooling regime shift. This period also witnesses the widespread dispersal of rich barrows with bronze objects, the onset of cremation burials, and an increase in the production of gold and amber objects, as well as axes, swords, and daggers (Feeser et al., 2019; Kneisel et al., 2019). Our data showed that one of the most significant changes was an increase in house sizes, with the largest three-aisled houses measuring up to 496 m^2 during ENBA II. Concurrent with this increase in house sizes, the frequency of three-aisled houses peaked. The repopulation and redistribution of wealth after ~1450 BCE underscored the remarkable resilience and adaptability of the ENBA communities in the face of climate change.

However, some houses during ENBA II–III became exceedingly small, ranging 9–20 m^2. Such small houses point to either a stratified distribution of wealth or outhouses (Earle, 2002; Kristiansen, 2010; Mikkelsen, 2013), requiring further analysis. Settlements during this period vary in organisation, with larger and smaller longhouses and economic buildings sometimes grouped as smaller hamlets or even villages (Artursson, 2015). Furthermore, the maritime sphere is strategically utilised and intensified, as well as finance decentralise chiefdom-like societies emerge that are dependent on trade and, possibly, slave labour, which could explain the increase in house size variation (Ling et al., 2018, 2022; Mikkelsen, 2013).

5.2.2. *Southern Norway*

Economic transformations: A new agropastoral economy spread in southern Norway during the LN (Prescott, 2020), as evidenced by directly dated cereals and our spatial population growth rates. This aligns well with earlier research, which showed intensified woodland clearance, the emergence of heathlands (Hjelle et al., 2016; Prescott, 2005, Prøsch-Danielsen, 2000, 2020), and the occurrence of cereals and ribwort plantain found in pollen and macro samples across the region (Hjelle et al., 2006). Archaeological evidence of cereals at sites in the western region at 2450–2350 BCE and in the Oslo fjord region at 2150–2050 BCE also supports this hypothesis (Nielsen et al., 2019).

An initial migrating phase of smaller Bell Beaker groups may play a role in the spread of farming (Holberg, 2000; Prescott and Glørstad, 2015; Skjølsvold, 1977), as they prospect for metal sources and establish a lasting infrastructure for exchange (Melheim and Prescott, 2016). Many flint daggers found along the Norwegian coast (Apel, 2001) and other objects made in a bifacial technique, such as Bell Beaker-type arrowheads (Østmo, 2005), point to well-developed exchange networks. Our study unveiled a distinct cooling period that occurred in 2350 BC, affecting regions 55–60°N. This may have led to intensified flows of new migrating groups to southern Norway, possibly leading to an intensification of the subsistence economy in Norway around 2200–2000 BCE (Austvoll, 2021). This interpretation would suggest that the agropastoral potential in western Norway, along with other ample resources, such as hunting (e.g. Indrelid, 1994; Finstad et al., 2018) may have acted as an attractive pull-factor for migrations.

Settlement reorganisation: Our large-scale analysis demonstrated that two-aisled houses drastically increased after 2300 BCE in southern Norway, which was at the same time as they increased in southern Scandinavia (cf. Austvoll, 2021). At the turn of the ENBA, there seem to be less activity in the region, indicated by a decrease in the number of longhouses and burials (Austvoll, 2021). In the inland fjord districts of western Norway, however, there are indications of increased utilisation of outfield resources. This is observed through a more uniform distribution and construction of two-aisled longhouses and hut-like structures, as well as the deposition of early metal artifacts. These patterns can be linked to population movements, as communities could had been pushed towards more marginal areas, leading to changes in settlement patterns and strategies for resource use. As shown in Fig. 6C, we detected no significant population decline during the ENBA but a continued steady growth. By ENBA II (1500 BCE), Southern Norway transforms to a fully-fledged Nordic Bronze Age system with the emergence of monumental earthen burial mounds, similar to those in southern Scandinavia, the disappearance of two-aisled houses, and a full transformation towards three-aisled houses.

Orientation of houses: Our analysis indicated that a significant portion of LN and ENBA houses in southern Scandinavia and southern Norway were constructed in an east-west orientation. The change in orientation can be attributed to the prevailing winds in the region, which make the east-west orientation more stable against the overall airflow (Topping, 1996). The location of houses also played a role, with many of the LN and ENBA strategically placed on the northern side of the fjords to take advantage of the sun's direction, which creates warmer vegetation zones (Moen, 1999). Austvoll (2021) noted that in south-western Norway, the earliest LN longhouses often had curved gable walls that created hipped roofs, which may have been sturdier against intense winds. Later two-aisled longhouses often had straight gable walls, which may have been easier to construct but more prone to damage from intense winds. However, the limited data availability restricts the ability to identify a statistical pattern or arrive at definitive conclusions regarding the relationships between architectonic features and climatic factors.

5.2.3. Arctic Norway

Economic transformations: In contrast to the distinct changes to the economy and social organisation following the introduction of agriculture by Neolithic communities to southern Scandinavia, the Arctic region displayed continuity in adaptive strategies, settlement patterns and demography. Foraging remained the dominant adaptive strategy at least into the late Iron Age when Norse agricultural settlers expanded northwards, yet foraging constituted a major economic pursuit also during the Medieval period, when state control, taxation, and industrial fisheries associated with the Hanseatic trade become more pronounced in the Arctic.

In a European context, food production arrived late and gained limited importance to the population of Arctic Norway during the LN and ENBA. There appears to be limited influx or local experimentation with food production in the most favourable coastal areas near the Arctic Circle, specifically the Helgeland region, which shows the highest concentration of Neolithic stray finds and trade goods in northern Norway (Valen, 2012). These findings suggest contact, influx, or admixture with southern Scandinavian agriculturalists. The Arctic has produced the oldest evidence of cultivation, with ard plough marks dated to 2000 BCE at Myrmoen site, Vefsn Municipality (Berglund and Solem, 2018). This site predates any other currently known food production activities within the region by approximately 500 years, as the Stiurhellaren rockshelter (Rana Municipality) produces both domestic animals (*Ovis* sp.) and cereals (*Hordeum* sp.), dated to 1500 BCE (Hultgreen et al., 1985). Following that period, scattered indications of experimentation with small-scale pastoralism can be observed along the Arctic western coast. However, actual farm settlements, which resemble and are associated with the Nordic Bronze complex, are only evident from the final centuries of the Bronze Age and become more widespread during the Early Iron Age (Arntzen, 2012).

The archaeobotanical evidence aligns with the material culture, indicating that evidence of crop cultivation remains sparse before the Pre-Roman Iron Age. Agricultural practices begin to spread more widely, although they still maintain a patchy presence on the western Arctic coast of Norway. Hulled barley (*Hordeum vulgare* var. vulgare) is the pioneering crop and remains the dominant cultivar throughout prehistory, yet naked barley (*Hordeum vulgare* var. *nudum*) and emmer (*Triticum dicoccum*) may also have been cultivated (Jensen, 2020). Wheat is currently only known from the Pre-Roman Iron Age (Jensen, 2012).

The prehistoric attempts at Arctic agriculture are discontinuous including periods of abandonment (Jensen, 2020). The patchy and scarce evidence for food production, limited to particularly favourable sites, and subject to discontinuity, reflects the return to more dedicated foraging economies. Divergent patterns in the types and functions of pottery are evident across Arctic Norway, including among mobile foragers and sedentary fisher-farmer communities (Pääkkönen et al., 2018). The discontinuous nature of pottery traditions (Jørgensen et al., 2023) reinforces the notion of local experimentation and/or sporadic, low-grade influx of agriculturalists.

While agricultural sites arguably are underrepresented in the current archaeological record of Arctic Norway due to investigation bias (e.g., Arntzen, 2015), prehistoric agriculture has a patchy distribution and secondary importance to foraging marine resources. Over time, an economic transformation emerges, signifying the essential way of life in coastal Arctic Norway, the evolution of the 'fisher-farmer' adaptation (Bertelsen, 2005). This economic system primarily relies on foraging, particularly fishing, and is supplemented by pastoral activities. Current evidence suggests sheep are present at least from the initial Bronze Age, and cattle from the Early Iron Age. This combination proves to be an ideal economic strategy on the outer coast. Grazing sheep (and later cattle) can make use of the minimal terrestrial productivity of the rugged islands, which are unsuitable for cereal production. Simultaneously, this strategy offers an important economic benefit and serves as a caloric risk reduction strategy to supplement potential shortfalls in marine foraging. This has remained the dominant adaptation among sedentary communities in Arctic Norway up to modern times.

6. Conclusions

This study investigated the impact of key mid and late-Holocene climate shifts in high-latitude regions of southern and north-western Scandinavia on the demographic trends and adaptive responses of Neolithic and Early Nordic Bronze Age societies (~4100–1100 BCE). It revealed a clear lateral zonation, with a variation in the duration and timing of the HTM. The HTM was particularly prominent in southern and central Scandinavia, leading to warmer summers for these areas. While it began around 6150–6050 BCE in southern Scandinavia, agriculture was not adopted in this area until around 4000 BCE. Therefore, this study asserted that the temporal coincidence of multiple accumulating and mutually reinforcing factors, including the HTM, the presence of arable land, and increasing demographic pressures and influences from central Europe, collectively contributed to the diffusion of farming practices.

Our analysis showed a more robust chronology of socio-economic trends, emphasising the significance of ^{14}C date contexts when modelling both SPDs and HPDs. Early Neolithic societies engaged in farming practices for approximately 300 years before establishing permanent settlements in the region. During EN Ib, several significant developments occurred, including large-scale crop cultivation (HPD of *3820–3790* BCE), the widespread use of permanent two-aisled houses (HPD of *3700–3660* BCE), and significant population growth. The study further revealed that the climate regime shift around 4.2 ka BP (2250 BCE), the coolest since the 6250 BCE (8.2 ka BP) event, initiated a lasting decline in summer temperatures from around 3450–1450 BCE, potentially leading to the risks of food shortages. In southern Scandinavia, human communities responded by ensuring the prolonged continuity of settlement sites, advancing towards sedentary lifestyles, diversifying crops, and storing them. The latter was achieved, for example, through the development of houses with sunken floors (HPD of *2290–2215* BCE). Around 2300 BCE, a group of Late Neolithic farmers migrated to southern Norway. Despite the likelihood of a not-too-severe cooling period, the population rapidly grew in both southern Scandinavia and southern Norway, demonstrating the high resilience of LN societies. Moreover, the local metal production on northern Jutland facilitated intensified networks with the Únětice culture in central Europe, resulting in newfound economic wealth, an increase in house sizes, and population growth. In Arctic Norway, a different scenario emerged. Foraging remained the primary adaptation for millennia, alongside farming, reflecting economic diversification as a strategy for risk reduction rather than intensification.

Furthermore, severe drops in summer temperature registered between 1850 and 1450 BCE led to short-term regression phases in the population in southern Scandinavia and Arctic Norway. Coupled with the collapse of the Únětice culture in central Europe, the population reached a bottleneck around 1600–1500 BCE. Subsequently, communities now primarily lived in large three-aisled houses (HPD of *1475–1450* BCE) in southern Scandinavia and southern Norway, which remained a common house type throughout the Bronze Age and beyond. The end of the prolonged cooling period around 1450 BCE was marked by repopulation and redistribution of wealth. Thus, high-latitudinal agricultural communities showed extremely high resilience towards climate disturbances.

The findings of this study shed new light on the ability of Neolithic and Bronze Age societies to navigate and adapt to changing socio-environmental conditions. Future research should direct its attention toward ecodynamics at more localised scales, including migration patterns. A detailed investigation into local house development, including the function of small three-aisled houses, could yield a more nuanced understanding of the complex interplay between human societies and their environments across various regions in southern and north-western Scandinavia over time. The findings of this study can have implications for contemporary societies facing similar challenges in adapting to changing environments and developing sustainable ways of living.

Author contributions

MMEB: Conceptualisation, archaeological data compilation (^{14}C dates and houses across the study area, supplemented the Danish dataset from excavation reports); formal data analysis; investigation; methodology; visualisation; supplementary data, roles/writing - original draft. **KIA**: Supplied a data set ^{14}C dates and houses from southern Norway; writing of the relevant sections. **EJ**: Supplied an unpublished data set of Arctic Norway ^{14}C dates; writing of the relevant sections. **SV**: Visualisation; supplied an unpublished data set of Eastern Norway ^{14}C dates. **JK**: Visualisation; helped with her expertise in Bronze Age archaeology. **MW**: Funding acquisition; visualisation; writing of the relevant sections. All authors reviewed the manuscript.Competing Interest Statement.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data and models are included in the submission

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.quascirev.2023.108391.

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