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Late Neolithic and Chalcolithic maritime resilience? The 4.2 ka BP event and its implications for environments and societies in Northwest Europe

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Abstract

This paper deals with prehistoric communities at the end of the 3rd millennium BC in Northwest Europe in relation to the 4.2 ka BP climatic event. In particular, the question of the resilience of these communities to climatic change will be studied here by comparing various climatic records and analysing specific archaeological parameters for social and cultural change. These parameters include the duration and intensity of settlement occupation, the variability of subsistence activities (*e.g.* cereal cultivation, animal husbandry, hunting, fishing, and gathering) and the connectedness of communities within exchange networks. Rather than answering the often-asked yes/no question with regard to human–environment relations, our research asks what effect resulted from the 4.2 ka BP climatic event, and, from the perspective of resilience, how did communities adopt to these changes in their practices and cultural choices during the later 3rd millennium BC.

In short, we maintain that climate change took place at the end of the 3rd millennium BC, but the changes in humidity and temperature with their effects on vegetation were probably regionally varied across Northwest Europe. We also observe that the studied communities developed differently during the second half of the 3rd millennium BC. On the one hand, we identify new food storage and house building techniques in the Low Countries and Schleswig-Holstein and, on the other hand, substantiate population decrease on the Orkney Islands around 2300 BC. Finally, we note a development of the Bell Beaker phenomenon into an Early Bronze Age *maritory* of connected communities across the North Sea, in which these communities expressed their resilience to climate change.

1. Introduction

From *ca.* 2600 BC onwards, prehistoric communities in Western and Central Europe exhibit large similarities in funerary practices and material culture, often labelled as the 'Bell Beaker phenomenon' (*e.g.* Vander Linden 2013). On the Iberian Peninsula, the end of this phenomenon is dated around 2200 BC with the rise of the El Argar civilisation. This coincides with a significant transformation in social organisation, settlement structure and food economy towards increased hierarchisation, centralisation and a surplus economy (Lull *et al* 2015). In other areas of Europe, this change is less clear cut and the Bell Beaker phenomenon seems to last until 2000 BC or even 1950 BC. The role of climate in population decline on the Iberian Peninsula, as well as the resilience of prehistoric communities, is a topic of current debate (*e.g.* Blanco-Gonzalez *et al* 2018, Hinz *et al* 2019, Schirrmacher *et al* 2020). Specifically, an abrupt climatic event, commonly known as the '4.2 ka BP event', had a well-attested influence on human society in large parts of the world. This particular climatic event was identified in North Atlantic marine sediments in the 1990s (Bond *et al* 2001)—recently also in the North Atlantic (Bradley and Bakke 2019)—and has also been related for a long time to large scale social changes in the Eastern Mediterranean, the Near East and Southeast Asia (Walker *et al* 2018, 217). In these particular regions of the world, this climatic event lasted from 4400 to 3850 BP (*ca.* 2450–1900 BC), led to severe droughts in already arid landscapes, and is said to have caused the collapse of, amongst others, the Akkadian Empire (Weiss 2015). This latter effect of climate change, a major socio-cultural transformation, was nuanced recently by Cookson *et al* (2019), who see both continuity in the occupation of certain sites as well as the effects of climate change on agricultural practices around 2250 BCE.

A relationship between this particular climatic event and cultural change has also been on the mind of several archaeologists in Central Europe, thinking along similar lines about the Near East and the Iberian Peninsula. In such light, they argue, we can see the development of the Southern German Early Bronze Age and the Únětice culture in Central Europe succeeding the Bell Beaker phenomenon (*e.g.* papers in Meller *et al* 2015) or decreasing human activity in Thy, northern Denmark (*e.g.* Andersen 1993). They regard climatic change as having played a significant part in the demise of this exchange network that is associated with the development of new socio-political entities. Others argue against such a view and observe strong regional differentiation with quite different developments. For instance, Müller (2015) conducted a study, comparing North Jutland, the South Cimbrian Peninsula, and the Central German Middle Elbe-Saale region (Mittelelbe-Saale-Gebiet). He focused primarily on artefacts and burial evidence associated with the Bell Beaker phenomenon. Within this north-south transect, different influences of the 4.2 ka BP event were postulated for societal development (Müller 2015).

In order to move this discussion forward, and to provide a different perspective, we focus on the resilience of Late Neolithic communities in Northwest Europe to climate change. This paper will review both climatic and archaeological evidence from several areas in Northwest Europe to provide some clarity and possible answers to the question on variability during this transition, and understand the resilience of a society towards climate change.

As global environmental phenomena are recently receiving new attention, aiming at a better understanding of how past societies coped with adverse climate change with respect to our present-day challenge (*e.g.* Weiss 2016), it becomes increasingly compelling to study the varied social mechanisms and effects from comparative regional scales. In particular, the extensive scale of climatic changes around 2200 BC and the comparability of communities taking part in the Bell Beaker cultural phenomenon make this an excellent case example to study the various responses to abrupt climate change in the past.

Recently, the climatic changes around 2200 BC have been the centre of several discussions beyond the transformations in prehistoric civilisations. For instance, geologists have proposed the subdivision of the Holocene epoch into three global stages, the Greenlandian, Northgrippian and the Meghalayan stages (Cohen *et al* 2018). Based on the observed global climatic changes, these stages replace the previously informal scheme of Early, Middle and Late Holocene. The change from the Northgrippian to the Meghalayan stage takes place during 'the 4.2 ka BP event', based on particular changes in temperature and precipitation, as determined from a particular Indian stalagmite (Walker *et al* 2018, 216–218).

Similarly, palaeo-ecologists have studied the 3rd millennium BC from the perspective of changes in vegetation. In Northern Europe, where most of this research has been carried out, the 3rd millennium is part of the Subboreal stage. The Subboreal is characterised by a steady decrease in *Ulmus* and *Tilia* pollen that is visible in many pollen-diagrams across Northwest Europe, indicating an opening of primary woodland. The opening of woodland is often attributed to a combination of both increased human impact and a long-term change in climate. These two processes are difficult to disentangle (Zagwijn 1994, 68), but both operate on a long timescale, and do not necessarily reflect the rapid climatic change of the 4.2 ka BP event. As Walker *et al* (2018, 214) also states, it is, however, unclear at the moment how different regional developments in climatic conditions and vegetation, such as the developing Subboreal in Northwest and Central Europe, relate to the 4.2 ka BP climate event.

In this paper, we will test the hypothesis that the climate change described as the '4.2 ka BP event' led to the end of the Bell Beaker phenomenon in Northwest Europe after 2200 BC. This hypothesis will be tested by reviewing the climatic evidence from a Northwest European perspective and reviewing the changes that took place around 2200 BC for regional communities across Northwest Europe. We keep in mind that the Bell Beaker phenomenon is a diversified social construct, which includes dense Bell Beaker style distribution areas as well as areas, in which only a few Bell Beakers are integrated into the local cultural environments. Therefore, an overview of the Bell Beaker phenomenon in the various case studies is also provided.

First, some expectations and basic assumptions will be presented concerning the concept of resilience and the relationship between climatic and archaeological parameters. After this, an assessment of the existing climatic evidence will be introduced for changes taking place at the end of the 3rd millennium BC in Northwest Europe, including marine archives from the Northeast Atlantic. Subsequently, archaeological evidence for change and continuity, in particular the occupation period and the abandonment of settlements and changes in subsistence economy, will be discussed.

This paper combines arguments and results from both environmental sciences, where the common time notation is BP (before present), and archaeology, which primarily uses BCE (Before Common Era) and reserves BP for uncalibrated radiocarbon dates. Additionally, distinct time periods used in archaeology are regionally varied, based on particular human practices, such as the presence of agriculture (Neolithic), the first appearance of particular materials (Chalcolithic for copper) or cultural expressions such as the Bell Beaker phenomenon. In this paper, the chronological framework is based on the works of Müller *et al* (2010), Louwe Kooijmans *et al* (2005) and Allen *et al* (2012). The Bell Beaker phenomenon is internationally dated between 2600 and 2000 BC, and as such it falls within the Late Neolithic B in the Low Countries, the Chalcolithic in Britain, and the Late Neolithic I in Northern Germany. Many discussions exist with regard to the regional chronological development and finding the 'earliest Bell Beaker' (*e.g.* Müller and Van Willigen 2001, Beckerman 2012, Healy 2012, Cardoso 2014, Großmann 2016), potentially revising this simple periodisation (see figure 1). However, using this variability in regional temporal developments during the later 3rd millennium BC in understanding changing exchange networks has not been previously attempted.

2. Methodology

This study compares archaeological data against a background of regional climate change. The archaeological data used is primarily based on published sources from excavation reports and synthetic monographs. Below, the various parameters and their data sources are explained in more detail. By using the concept of resilience, we aim to grasp the relationship between society and climate in Northwest Europe. As Clare/Weninger (2010, 286–7) state: '[…] the societal impact of catastrophic events is not solely a product of the physical event itself. It is equally attributable to the prevailing properties of the afflicted community […].'

2.1. Resilience

Resilience is the central concept of this paper. This term is adopted from early ecosystems research (e.g. Holling 1973), where it is used to study the changing relationships between various 'domains of attraction' within an ecological system, and the need for persistence of the various agents within this ecosystem, at the fear of extinction. These changing relationships are neither continuously gradual nor consistently chaotic, but instead episodic and punctuated. Within socio-environmental research we can further define this as the ability of groups or communities to cope with external stresses and disturbances as a result of, in this case, climate change (Adger 2000) and the transformations of society as a result. This ability to transform is based on the dependence of these communities on their ecosystem and natural resources. As such it relates to the 'functioning' and adaptability of communities instead of their ability to withstand these changes through stability.

Transferring this concept to archaeology allows for the study of the long-term perspective of this adaptability of communities to their environment, as Redman/Kinzig (2003) write. It means that archaeologically, we should <u>not</u> be looking for situations of 'no cultural or social change' where we see a sudden change in climatic records as evidence for resilience. Instead, we should look at the changing practices of communities and engagement with the environment in correlation to this climatic change. Thus, the central question arises concerning what kind of practices and engagements can be identified and how these can be understood from the perspective of correlations with a changing climate.

These correlations can be studied by focusing on the dependence of these communities on their ecosystem and natural resources. In particular, studied aspects include food security, shelter, social relations and coping with hazards (*e.g.* Adger 2000, 354, Samson *et al* 2015). Several archaeological case studies have already been published, focusing on resilience to climate change, primarily using case studies from the Near East, either specifically adopting Holling's methodology (Redman and Kinzig 2003, 13–15) or adopting the perspective to understand phases of settlement occupation, abandonment (*e.g.* Flohr *et al* 2016) and agricultural practices (*e.g.* Cookson *et al* 2019). Samson *et al* (2015) study the resilience of housebuilding strategies under the influence of climate change in the face of modern hazards in the Caribbean. The work of Bicho *et al* (2016) takes the concept of resilience one step further, without a climatic cause in the background. They focus on the ecological possibilities of particular coastal estuarine regions in southern Portugal and their ability to accommodate the continuation of a 'Mesolithic' culinary lifestyle, during externally driven cultural changes and the integration of Neolithic elements.

In short, external forces, such as climate, can be expected to have had an effect on prehistoric communities, their behaviour and resilience in terms of changing food production, consumption and storage activities, house building practices, settlement occupation and the structure of exchange networks.

In this study, all these aspects will be examined more closely for the later 3rd millennium BC in Northwest Europe, focusing on settlement occupation, housebuilding practices, changes in the subsistence economies of these communities and the development of particular exchange networks (known as the Bell Beaker phenomenon, discussed below). The question whether climate change is responsible for these transformations is not relevant from a perspective of resilience. A focus is rather placed on the question how these aspects change and how resilient these communities are in correlation to climatic changes. What additional factors (social, economic,

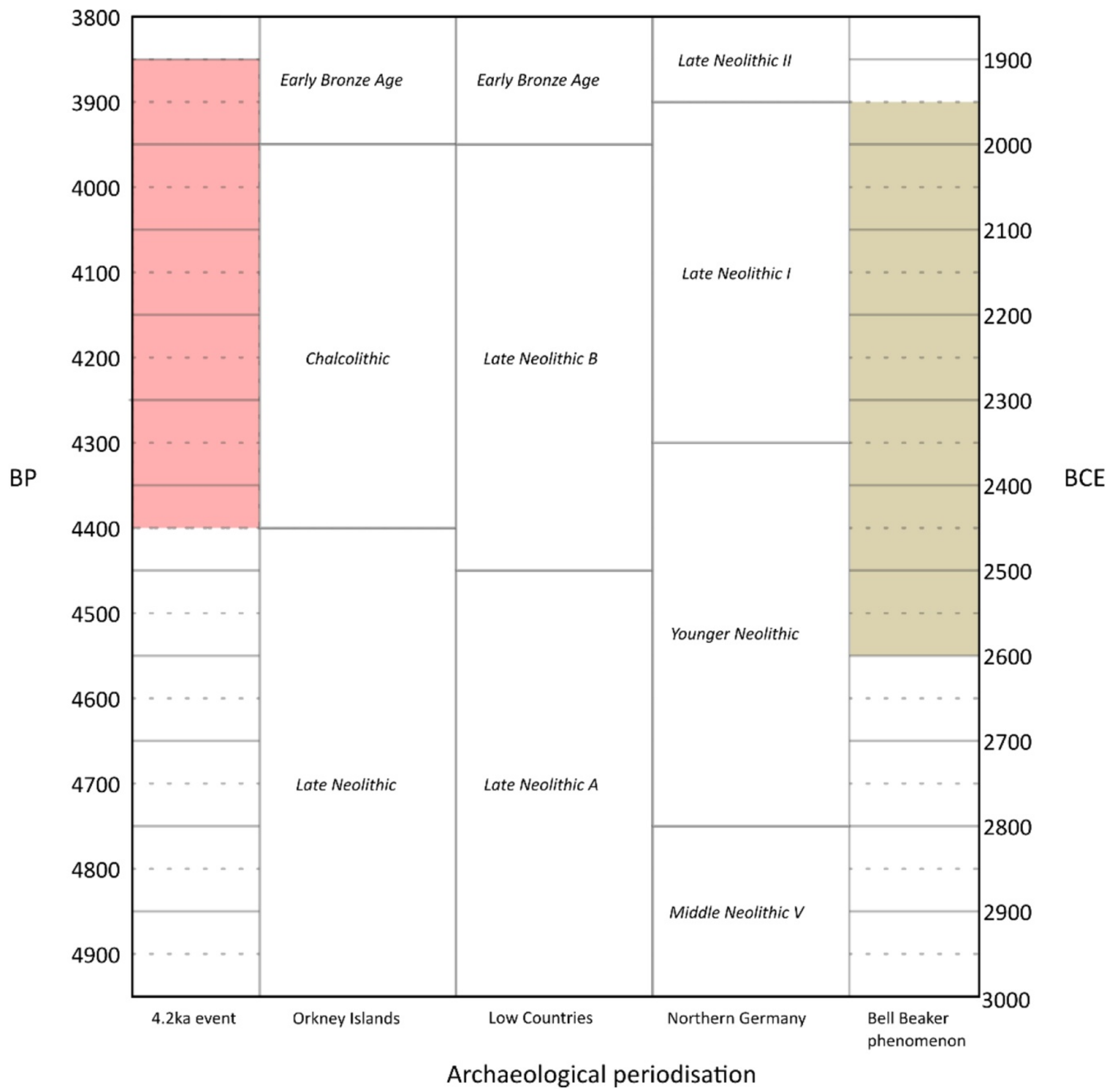

Figure 1. Comparative periodisation for the 4.2 ka BP event, the different study areas and the Bell Beaker phenomenon (based on Jalali *et al* 2019, Allen *et al* 2012; Louwe Kooijmans *et al* 2005, Müller *et al* 2010, Kleijne 2019 respectively).

or ideological) were involved in these transformations will also be discussed. As previous authors have already argued, socio-political (*e.g.* Needham 2005), economic (*e.g.* Brozio *et al* 2019) and ideological (*e.g.* Fokkens 1999) factors played a role in the transformation of society at the end of the 3rd millennium BC.

2.2. Methods explained

We study settlement activities by looking at the occupation history of settlements throughout the 3rd millennium BC, noting the start and ending of settlements and the ways in which settlement practices and traditions are continued, changed, or abandoned. If patterns are visible across an entire region, with occupation ending at all settlements, a case can be made for an external driver. When climate indicators show a concurrent change, and other possible external drivers (such as warfare, disease, or demography) are absent, we can correlate these two observations. When occupation and settlement practices change less dramatically or do not change at all, while climate does change, we argue for resilience. By using Bayesian modelling (see Bayliss *et al* 2007 and Bronk Ramsey 2009) and the aoristic method (see Mischka 2004, Crema 2012), we are able to provide the most precise chronological resolution to correlate the climatic and archaeological datasets.

Subsistence strategies are studied by comparing the records for botanical and zoological datasets from archaeological excavations, complemented with evidence such as pottery residues and food crusts, cattle hoofprints, plough marks, palynological evidence and certain finds associated with subsistence. Particularly important in identifying resilience to climate change are the (lack of) diversity in produced and consumed animal and plant species, and the introduction of new animal and plant species within the human diet. Both will be assessed for their chronological relevance based on the phasing of settlements mentioned above.

An analysis of the exchange networks of ideas and objects will mainly focus on the development of the

Figure 2. Study areas within Northwest Europe and climatic archives mentioned in the text.

Bell Beaker phenomenon in the three study areas. The Bell Beaker phenomenon, in itself, was first identified at the turn of the 20th century by various archaeologists, based on a particular shape of pottery vessel decorated with spatula impressions in various banded and geometric motifs (*e.g.* Reinecke 1900). Since then, many scholars have identified numerous associations with other typical objects and, in particular, with individual inhumation burials as central elements, leading to the identification of 'Bell Beaker people' travelling across Europe (Childe 1958). Later, the definition of a 'Bell Beaker package' of grave goods, including a pottery vessel, a copper dagger and/or copper working tools, stone archery equipment, such as wristguards and arrowheads, and personal ornaments of precious raw materials, such as gold (Burgess and Shennan 1976, Fokkens 1999), was developed. More recently, this grave set has been regarded as only a particular aspect of regional communities, primarily expressed in the funerary domain; hence, it is known as the 'Bell Beaker phenomenon' instead (Strahm 1995, Vander Linden 2006).

Regional studies have defined various chronological phases within the Bell Beaker phenomenon, based on the objects themselves and the patterns by which these objects were deposited in graves (*e.g.* Needham 2005). Several studies have also specifically pointed out that Northwest European communities developed intense coastal and maritime elite exchange networks during this time period (Abercromby 1912, Van De Noort 2006, Needham 2009, Wilkin and Vander Linden 2015). This hypothesis led us to choose three regions within this exchange network.

The Bell Beaker phenomenon will be analysed by looking at the regional or long-distance character of the exchange networks, the intensity of the exchanges themselves in terms of new objects and ideas, and the changing funerary practices associated with these objects and ideas. An understanding of the changes in the focus, intensity and practices of this exchange network will be used to study the development of these maritime communities as an aspect of their resilience.

In the following paragraphs, we will first review the evidence for climatic change moving from the marine records to specific regional continental proxies. After this climatic framework, the specific archaeological evidence for settlement activity, subsistence economy and the Bell Beaker exchange network will be reviewed. Subsequently, this review will study the Orkney Islands, the Low Countries and Schleswig-Holstein (see figure 2). Thereafter, these parameters will be investigated and their relationships with each other and with the changing climate at the end of the 3rd millennium BC will be discussed.

Having explained our premises for this study and the concept of resilience that relates society and archaeological data to climate change, we will now turn to the climatic records themselves. In order to understand climate change in Northwest Europe around 4200 BP, we will review various climatic records from marine and terrestrial sources. The most suitable records are found in the marine archives of the North Atlantic Ocean, as these records often provide both quantitative and continuous reconstructions of temperature and precipitation changes without the distorting signals of human impact (e.g. Zagwijn 1994). These records, however, also convey a regional signal and thus cannot be used as a template for developments in other parts of Europe. While these records do not relate to a regional signal that directly influences communities in Northwest Europe, their significance lies in the clarity of their records and the ability to allow us to understand the environmental mechanisms at play here. Therefore, we will compare specific marine records to other regional terrestrial records, which were observed in proximity to our study areas in order to highlight the regional variability in climatic change and possible impacts on vegetation. In the paragraph following this, we then review the archaeological evidence in relation to these particular climate records.

The influential papers by Bond *et al* (1997), Bond *et al* (2001), based on micropalaeontological and sedimentological markers in northern North Atlantic sediments from two cores west of Ireland and west of Iceland, suggested a pervasive pattern of recurrent cooling phases within a period of roughly 1500 ± 500 years, leading to cooling events in the northern North Atlantic region. Based on a comparison with production rates of radiogenic nuclides of ^{10}Be and ^{14}C proxies, and comparing several cores with each other, the authors concluded that a decrease in the energy output of the sun with an influence on surface climate resulted in a decrease in temperatures. Because of the cyclicity and the mechanism proposed, this paper formed the basis for many of the discussions concerning worldwide climate variability during the Holocene. Specifically, Bond event 3 is dated to the later 3rd millennium BC (4.3–4.1 ka years calibrated BP, based on cores VM29-191 and VM28-14) and subsequently correlated to the subtropical, and possibly worldwide 4.2 ka BP event (Wanner *et al* 2008). Several other marine records from the North Atlantic exist that underline the widespread occurrence of this cold event. Berner *et al* (2008) reconstruct summer sea surface temperatures (SST) from a core in the subpolar North Atlantic (LO09-14; southwest of Iceland), and they note quasi cyclic temperature fluctuations in terms of 1–3 degrees C, superimposed to a general cooling trend as driven by decreasing insolation. Their Holocene Cooling Event 11 (HCE 11) dates between 4.5 and 4.2 ka BP and aligns with Bond event 3 (Berner *et al* 2008, figure 7). A detailed record by Andresen *et al* (2012), based on changes in planktonic foraminifera assemblages at a fjord site at the east coast of Greenland (core FOX04 G), reveals distinct changes in SST, marking three distinct climate intervals/zones. The transition from zone II to zone III falls around 4200 cal. yr BP. While zone II is characterised by delayed warm conditions of the Holocene Climate Optimum, a cooling is noted from zone IV (3600 BP) onwards, and possibly cooler indications already exist in zone III as well (Andresen *et al* 2012, 172). This is attributed to the advancing Greenland glacier ice sheet (the so-called Neoglacial cooling, see also MacKay *et al* 2018). Most recently, Jalali *et al* (2019) analysed two cores from the marine deposits north and south of Iceland and simultaneously reviewed the ocean circulation currents influencing climate in Northwest Europe. Their results also show a decrease in the SST of 2 degrees C around 4200 BP for the core north of Iceland. The particular currents around Iceland, however, demonstrate a more complex picture with the core south of Iceland showing inverse patterns with an increase in temperature around 4100 BP. This dipole pattern is probably the result of a weakened subpolar gyre circulation (and weaker North Atlantic meridional overturning) leading to enhanced wintertime North Atlantic anticyclone blocking over the NE Atlantic that is responsible for severe (cold and dry conditions) winters in Europe.

Concluding, several high-resolution cores have been examined that indicate a general trend of cyclical climatic changes. More important than cyclicity for our study is the regional importance of these records. The 4.2 ka BP event in these records, which manifests primarily as a decrease in the SST in the North Atlantic, was caused by a slowdown of the subpolar gyre, which, in itself, was primarily forced by a decrease in solar activity.

As stated above, it is clear that the mechanisms of solar (and orbital) forcing, influencing the atmospheric and oceanic circulation, caused cyclical climatic changes, of which the 4.2 ka BP event is one clear example. Studies that present datasets with a high-resolution chronology are, however, scarce (*cf* also Weinelt 2018). In order to see what effect these mechanisms had closer to the prehistoric communities in Northwest Europe, we now look at several cores (both marine and terrestrial) with high-resolution, taken from sediments in closer proximity to the environments in which human societies lived during the 3rd millennium BC. Here, we differentiate between the British Isles, Scandinavia, and the Low Countries. These cores are chosen in order to understand climate change with respect to Northern Germany, the Orkney Islands, and the Low Countries.

2.3. Scandinavia and Northern Germany

Butruille *et al* (2017) analysed sediments dating to the 3rd millennium BC using a core from the Skagerrak, north of Denmark. As such, this core is relevant for the study of socio-environmental relations in Northern Germany and Scandinavia during this time period. They reconstruct winter temperatures from trace metal and oxygen isotopic signatures of benthic foraminifera, supporting the occurrence of severe winters under NAO-like conditions. Their results show a decrease in both Intermediate winter temperatures (IWT) and in deep water temperatures (DWT) between 4300 and 3500 cal. yr BP, also correlating with Bond event 3 (Butruille *et al* 2017; figure 6). At Lake Bliden in Denmark, Olsen *et al* (2010) see a decrease in oxygen isotope values between 4300 and 4050 BP, pointing to a wetter period. However, an increase in nitrogen and sulphur isotope values indicates to the authors that seasonal variability in temperature and humidity increased (Olsen *et al* 2010, 338). Vorren *et al* (2007) studied the Sellevollmyra bog in Arctic Norway by analysing peat humification, LOI (Loss on Ignition), micro- and macrofossils and tephra. They identified two 'wet shift' periods between 4220 and 3810 BP, indicative of a climatic change with lower temperatures and moister conditions. In Schleswig-Holstein and Mecklenburg-Vorpommern, several lakes have accumulated yearly sedimentation (varves), making high-resolution climate reconstructions possible. Several studies use varve counting, thin-section analysis and elemental and isotopic analysis, in combination with palynological analysis. These multi-proxy analyses at Lake Woserin and Lake Belau primarily provide evidence for variability in human impact, instead of climate change (Feeser *et al* 2016, 960–961). Consequently, no major climatic change was observed in these records around 4.2 ka BP. Dörfler (2008) also reviewed the evidence for changes around 4.2 ka BP from other cores and comes to the conclusion that the visible palynological changes are primarily driven by in- and/or decreases in human activities in the landscape.

2.4. Britain and Ireland

Excellent British and Irish climate records are based on numerous peat bogs. Several important records were published in the last decades. A recent review of these records from Northern England and Central Ireland was carried out by Roland *et al* (2014), who summarised the chronological framework and climatic interpretations. Accordingly, a general trend is jointly recorded by the above-mentioned studies towards wetter and/or cooler conditions (Roland *et al* 2014, table 1). The chronological range of this climatic shift was primarily attributed using 14 C dates, falling between 4.6 and 3.9 ka BP, thus spanning a relatively wide range, making it impossible to precisely relate this chronologically to a potentially short-lived 4.2 ka BP event. Moreover, the methods of bulk 14 C dating and a focus on plant macrofossil analysis were deemed too insecure. In order to overcome this problem, to narrow down the chronological uncertainty, and to be able to better position these records in the 4.2 ka BP event discussion, Roland *et al* (2014) used the tephra of the Hekla-4 eruption (Larsen and Þórarinsson 1977, Pilcher *et al* 1996) as a marker dating around the same time as the 4.2 ka BP event in their analyses of two cores from Northern Ireland, potentially creating a more secure chronology for an understanding of the climatic changes. However, their proxy records (using peat humification, plant macrofossils and testate amoebae) and other more-securely dated contexts from Scotland and Northern England show no compelling evidence of general wetter and/or cooler conditions in the wider region. A more recent study by Jordan *et al* (2017) uses a combined elemental, isotopic and lipid biomarker approach on a radiocarbon-dated peat core from a coastal location in Western Ireland (Spiddal). In contrast to the previously mentioned studies, their analyses show a return towards a colder and wetter climate around 4170 cal yr BP. This transition is correlated to the 4.2 ka BP event by the authors. The discrepancy with the earlier findings by Roland *et al* (2014) are described as possible regional variation in the effect of climate change on the peat developments, but the different analytical methods might also contribute to the varying heterogeneity of signals.

2.5. Low Countries

From the Low Countries,[1] several cores from the remote Engbertdijksvenen site were analysed with the specific focus on understanding climate change during the Middle to Late Holocene period. Core ENG-XV (Blaauw *et al* 2004) was studied by using macro- and microfossil analysis and wiggle-matching of a large number of 14 C dates. In doing so, they created a high-resolution record of vegetation development in this peat bog. They show that a correlation exists between shifts towards a wetter environment and the rise in delta-14 C concentrations. As the latter proxy is caused by a variation in solar irradiation, this supports an argument in favour of solar forcing as a mechanism causing climatic changes. A minor wet-shift was recorded around 2310 cal BC in phase Eng-1, based on changes in the relative frequency of macro- and microfossils also correlated to a small change in delta-14 C. This is followed by a drier period around 2115 cal BC.

Summarizing, a critical element for the study of the 4.2 ka BP event is the use of chronological high-resolution datasets, using wiggle-matching or by taking the eruption of the Hekla volcano and its microtephra (*e.g.* Van Den Bogaard *et al* 2002) as a chronological marker. Secondly, it is imperative to understand the various origins of signals from various proxies, their seasonal biases, and how different proxies influence each other across time and space.

Several more general comments can be made with regard to the 4.2 ka BP event itself and the ways in which we have tried to understand it until now, before we can start analysing our archaeological data concerning the possible societal impacts of climatic changes. It is clear that terrestrial sediments present a difficult dataset, for which it is necessary to separate the human impact signal from the climatic signal with regard to vegetation or sedimentation changes in lakes. The high-resolution and well-dated peatlands of Great Britain and Ireland present an excellent opportunity to study the potential manifestation of the 4.2 ka BP event in the region, possibly documenting the timing and nature of its palaeohydrological effects and likely drivers. Problems with these high-resolution and multi-proxy signals are often their regional expressiveness. As climatic changes frequently manifest themselves in a time-transgressive and/or spatially variable way, further studies should

[1]Many palynological studies in the Netherlands have been directed at understanding vegetational development and its palaeogeographical implications. These cores do not have a high resolution and are thus not suitable for understanding climatic changes.

focus on both inter-site comparisons and understanding the mechanisms and possible time lags that underpin various proxies.

In the observations above, we have reviewed many studies dealing with high-resolution marine, lake sediment and peat archives that focus on understanding climatic change in relation to the 4.2 ka BP event. When we combine these types of evidence in a provisional model, we discern a climatic change, forced by orbital or solar mechanisms, leading to a change in sea surface temperatures and oceanic circulations. The effects of this primarily marine development on terrestrial climate are regionally varied across Northwest Europe, reflecting variations in the regional hydrology of these landscapes. In some areas, such as Central Ireland or Northern Germany, no clear effect is visible, while in other areas, such as the Low Countries and Norway, clear 'wet-shifts' have been recorded within precise chronologies.

3. Analysis: archaeology of the study areas

3.1. The Orkney Islands

Situated in the far North of the British Isles, human occupation on the Orkney Islands shows important developments during the 3rd millennium BC. During the earlier 3rd millennium BC, large stone-walled, nucleated settlements, such as Skara Brae, Ness of Brodgar and Barnhouse (associated with Grooved Ware pottery), were occupied intermittently until *ca.* 2400 BC (see figure 4; *cf* Bayliss *et al* 2017, 1182: figure 5). At Late Neolithic sites in the Orkney Islands, various sources of evidence point out that '[…] there was economic stability between the early and late Neolithic in this area, with no significant exploitation of wild terrestrial or marine fauna in either period […]' (Bishop 2015, 844).

Occupation lasted beyond the middle of the 3rd millennium BC only for two of these stone walled settlements: at Tofts Ness on Sanday and at Links of Noltland on Westray. At the latter, large stone houses are abandoned with a spectacular deer heap deposition, but some evidence for occupation also exists. In trench C, a cultivation soil developed on top of a stone wall, containing some Bell Beaker pottery (Clarke *et al* 2016, 60–61). Trench D also revealed a wall in a phase postdating the spectacular Late Neolithic settlement abandonment, preceded with evidence for ard and spade cultivation and the removal of wall stones (phase VII and VIII; Clarke *et al* 2016, illus. 5), signalling a renewed activity in this landscape during the Bell Beaker phase. Plant remains and animal bones have not been published yet.

At Tofts Ness, on mound 11, settlement evidence consists of a stone roundhouse structure covered by a settlement mound and various cultural layers. Late Neolithic occupation is present in the form of a midden sequence, covered by windblown sand. Habitation on this site continues into the Early Bronze Age. The Late Neolithic midden sequence, phase 2 of the site, produced cultural remains of both stone tools and pottery. The absence of Grooved Ware, so common on other settlements on the Orkneys, is remarkable. Instead, pottery decoration points towards maritime exchange networks with communities on the Shetlands (Dockrill 2007, 381). Plant remains at Tofts Ness show a predominance of naked barley (*Hordeum vulgare* var. *Nudum*), cultivated in a garden-like fashion using manuring (Dockrill and Bond 2009, 35). However, the animal remains from Tofts Ness show that the subsistence economy was not solely based on cereal cultivation and livestock. While cattle and sheep predominate the spectrum of land-based animals, the number of bird and fish remains indicate an important role for the fowling of various species of birds and marine fishing, primarily of large cod and ling (Dockrill and Bond 2009). It is clear that this settlement is characterised by a flexible subsistence economy.

As said, the 3rd millennium BC stone house settlements are typically associated with Grooved Ware pottery and stone artefacts (such as axes, maceheads and carved stone balls, *e.g.* Anderson-Whymark *et al* 2017). Pottery that can be characterised as inspired by the Bell Beaker phenomenon is found infrequently in the uppermost layers of a few settlements and as loose finds. This pottery often does not exhibit typical Bell Beaker attributes (thin-walls and S-shapes) but does show some stylistic similarities (geometric spatula decoration, *e.g.* Gibson 1984). Dating between 2100 and 1800 BC are two bronze daggers, a single flint dagger (all loose finds from marsh contexts *e.g.* Needham 2004, Frieman 2014) as well as several precious stone beads and golden artefacts from funerary contexts (*e.g.* Sheridan *et al* 2003). Material culture from the scarce number of settlements dating between 2400 and 2100 BC primarily illustrates exchanges of a regional nature (*e.g.* MacSween in Dockrill 2007).

Palynological evidence on the Orkney Islands generally shows a predominantly open and treeless landscape, dominated by herbaceous vegetation. This landscape developed since the first opening of the woodland during the earlier Neolithic and continued throughout the 3rd millennium BC. This is apparent from both on-site investigations (see Davidson and Jones 1985, 26–27) and from several recent peat cores (*e.g.* Farrell 2015).

A decrease in human activity was previously dated from 2000 BC onwards based on palynological evidence (Davidson and Jones 1985). By quantifying monument building and its special distribution as well as domestic patterns and comparing these results to palaeo-ecological evidence, Müller (1990) already stated that around 2300 BCE a steep decrease in economic and cultural activities took place. Bunting *et al* (2018) recently modelled vegetation development during the Neolithic on the Orkney Island. They state that no changes in land cover are visible

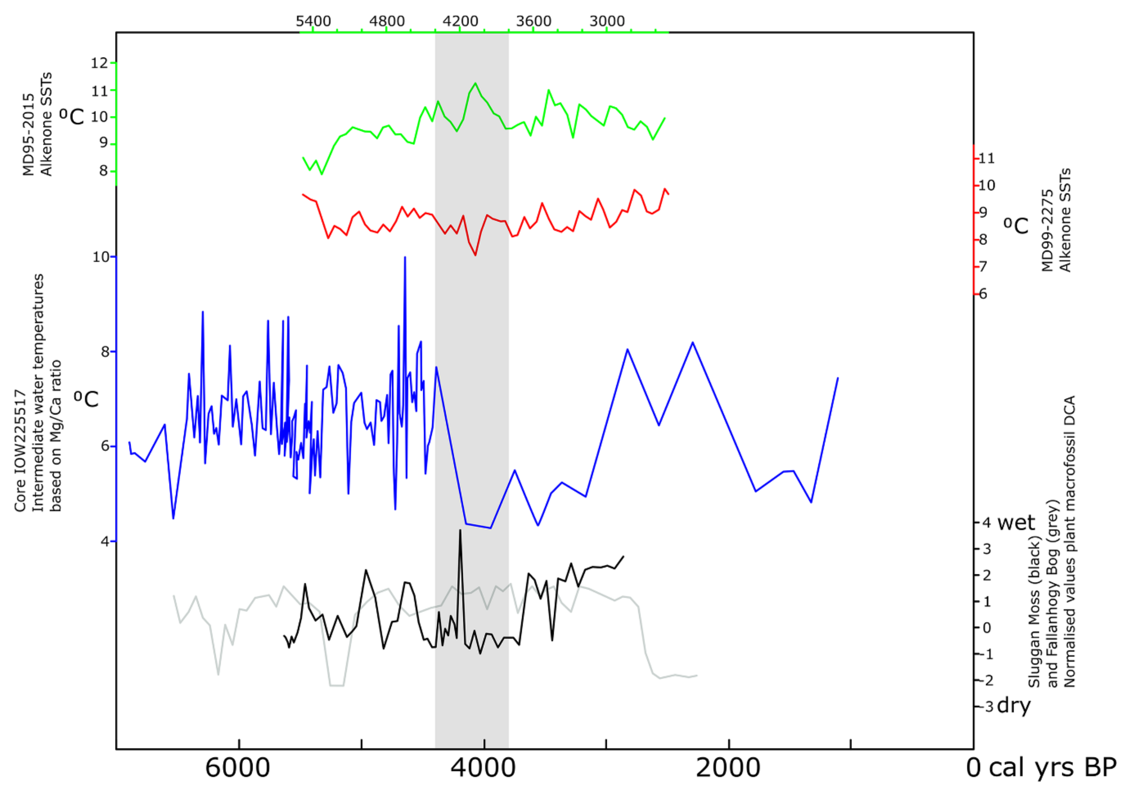

Figure 3. A comparison of the climate reconstructions by, from top to bottom. Jalali *et al* (2019) in green and red, Butruille *et al* (2017) in blue, and Roland *et al* (2014) in grey and black. The 4.2 ka BP event, shaded in grey, is given according to Jalali *et al* (2019).

that might be explained by climate change or abandonment associated with the final occupation of the stone-walled settlements around 2300 BC. They suggest a continuity of land use instead (Bunting *et al* 2018, 11). However, in their curves around the end of the 3rd millennium BC are a visible minor increase in the proportion of land area covered by pine-oak trees, both in lowland and upland landscapes (Bunting *et al* 2018, figures 4(b) and (c)), and some regional varying developments (Bunting *et al* 2018, figure 3) that might be more indicative of a decrease in human activity or changing land use practices.

3.2. The Low Countries

Bell Beaker settlements in the Low Countries are known primarily from the Western Netherlands (see Kleijne and Drenth 2019: figure 1; see also figure 5). Houses consist of rectangular wooden structures, with often preserved central posts and wall posts. The house plans show a continuous development from the earlier 3rd millennium BC onwards, as can also be illustrated by creating a comparative plot of the various Bayesian analyses that were carried out by Kleijne and Drenth (2019) in figure 6. Two-aisled plans, such as at Vlaardingen (phase 2), date between *ca.* 2600 and 2200 BC. Such simple house types continue to be built at Carnisselande (phase 3) between *ca.* 2200 and 2000 BC and change only slightly with the addition of an extra internal structure (possibly connected to storage facilities) and double wall-posts at, for instance, at Molenaarsgraaf (phase 1) and with a shift towards a (wider) three-aisled ground plan at Heiloo (phase 1) and Noordwijk (phase 1; Kleijne and Drenth 2019). Excavations often reveal house plans that are in many cases not contemporaneous, but probably successive. Settlements themselves seem to have been occupied for only one generation making any assessment of increasing or decreasing settlement intensity difficult.

The subsistence economy of Late Neolithic communities in the Low Countries is primarily based on arable farming and animal husbandry with cattle and sheep (Clason 1999). Examples of arable farming are the large plots of arable land at Velsen Westlaan 2 (Therkorn 2008, Kleijne 2015), Oostwoud (Fokkens *et al* 2017) and Noorderboekert (Knippenberg 2018). At these locations, extensive tracts of arable land often reveal multiple phased, criss-crossed plough marks. These sites are often situated in dynamic coastal landscapes, well-suited for cereal cultivation. On the less fertile sandy soils, a more pastoral economy is envisaged based on the continued openness of cultural landscapes and the maintenance of heathland, as also visible in pollen-diagrams (Doorenbosch 2013, 233–234). Both the gathering of wild resources and the fishing, hunting, and fowling of wild animals continue to be of importance (see also Fokkens *et al* 2016). At the site J97, a large number of fish weirs and fish traps were found dating to the later 3rd millennium BC (Bulten *et al* 2009) and at Molenaarsgraaf

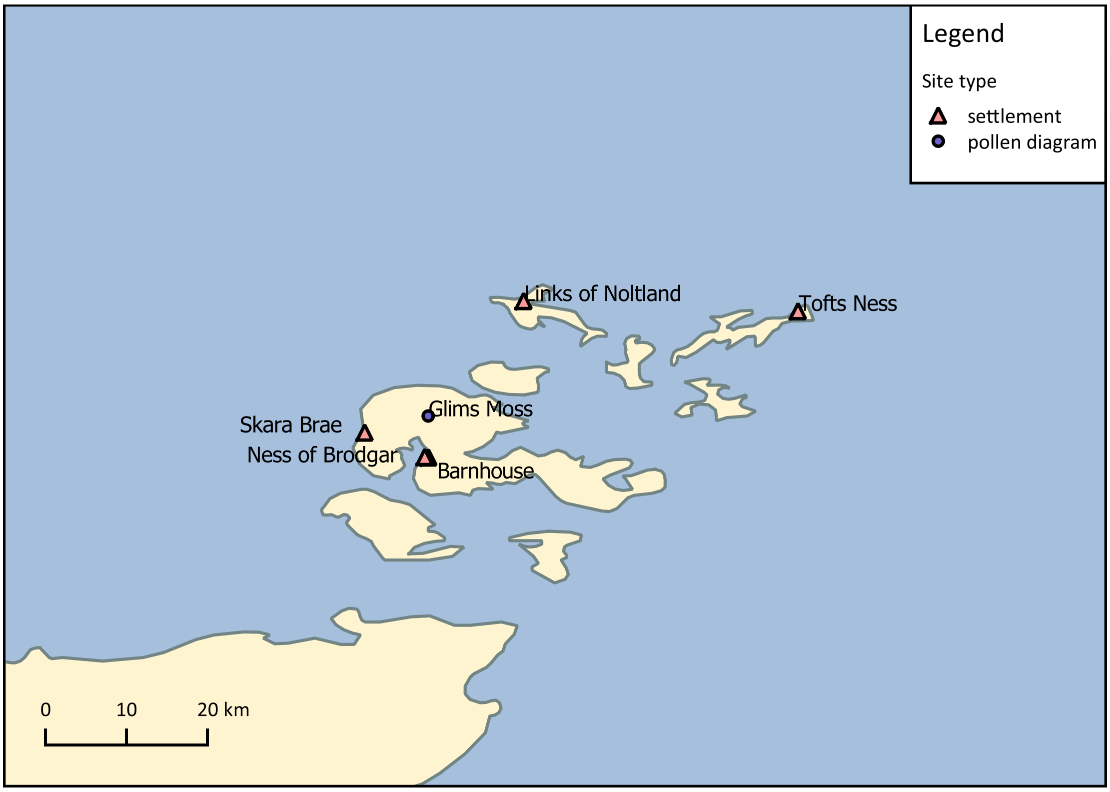

Figure 4. All the mentioned sites on the Orkney Islands.

a burial contained both a Bell Beaker vessel and a number of fish remains, fish hooks and possibly an antler-shaped fishing rod (Louwe Kooijmans 1974). Fish remains at settlements, such as Carnisselande, e.g. show that it formed an integral part of the subsistence economy (Moree *et al* 2010).

With regard to exchange networks, the communities in the Low Countries were well-integrated in the Bell Beaker network throughout the entire second half of the 3rd millennium BC. Settlement and funerary ceramics show a large degree of continuity, visible in the development of specific regional vessel types, such as Veluwe-style Bell Beakers, Potbekers and *Riesenbecher* from 2300 BC onwards, and the early introduction of Barbed Wire decorated vessels already around 2200 BC, as illustrated by the finds at Houten-Vleugel 20 (Besselsen and Van Der Heiden 2009) and Carnisselande phase 4. These various kinds of pottery are known from settlements as sherds or as complete vessels from carefully placed deposits. In the Low Countries, the number of Potbeker and Riesenbecher vessels from funerary contexts is relatively low (Kleijne 2019, 158–161). Despite the lack of naturally occurring ores, metal objects and evidence for the practice of metallurgy (in the form of cushion stones: Drenth *et al* 2013, but also a copper droplet from Carnisselande phase 3: Moree *et al* 2010) are found from 2500 BC onwards. The hoard of Wageningen (Butler 1990) exemplifies the introduction of new types of objects, such as halberds, and new kinds of metal alloys (arsenic copper and tin bronze) that date between 2100 and 1900 BC. To this same time period, we date the early *Schleifenkopfnadel* from St. Walrick (Butler and Van Der Waals 1966), the Exloo necklace (Haveman/Sheridan 2006) and the riveted dagger from Bargeroosterveld (Butler 1960). This dagger style, the needle type and the new objects and raw materials from the Wageningen hoard are commonly found in Central Europe from 2200 BC onwards (Gerloff 1975; Needham 2004), while the Exloo necklace with its faience and large amber beads (Haveman and Sheridan 2006) shows connections to rich Wessex burials in Britain.

3.3. Schleswig Holstein

Settlement activity in Schleswig-Holstein during the later 3rd millennium BC is characterised by small scale single farmsteads. Late Store Valby and Early Corded Ware settlements, where occupation ends around 2600 BC, have been found for instance at Oldenburg LA 232 and Brodersby-Schönhagen (Brozio *et al* 2019a, 2019b), but only settlement scatters are known from between 2600 and 2200 BC such as at Groß-Waabs (*e.g.* Arnold 1985). From 2200 BC, new indications for permanent occupation are known from Archsum LA65 ('Melenknop'; Kleijne *et al* in press), Flintbek LA20, (Zich 2000, Mischka 2011), Schoolbek and Harrislee (Ethelberg *et al* 2000, 165–172; see figure 7). In many instances, material culture or other kinds of dating evidence are lacking,

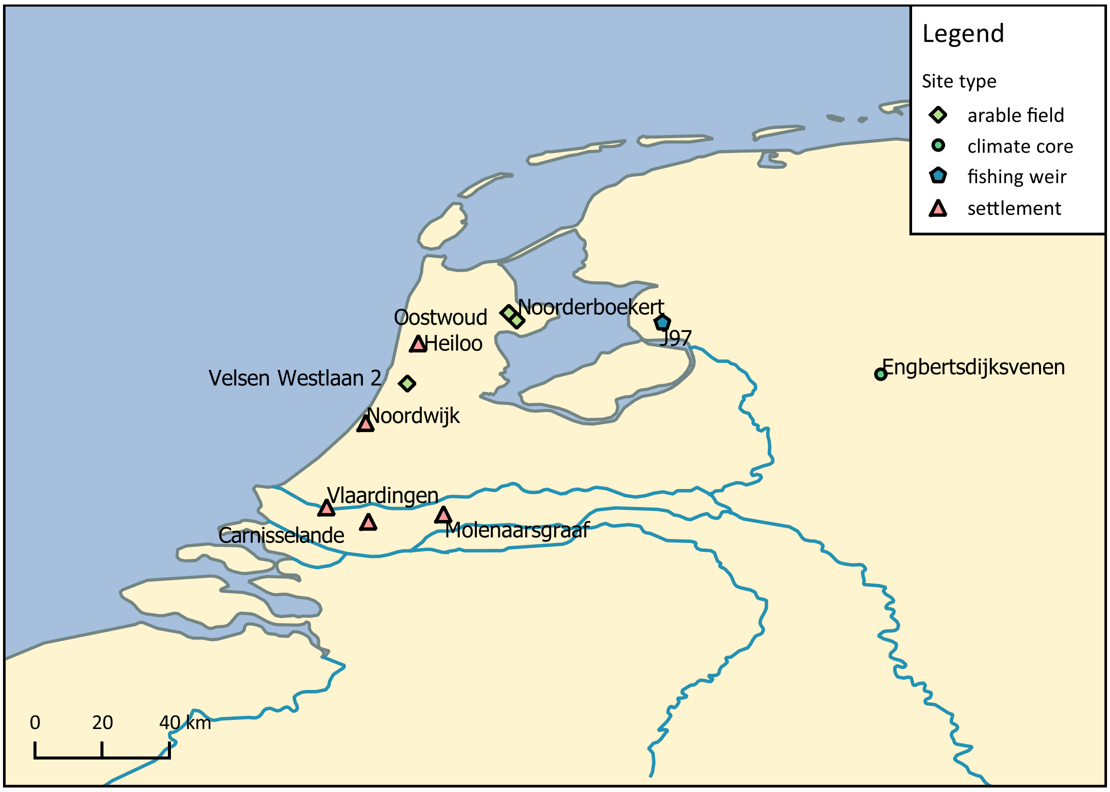

Figure 5. All the mentioned sites in the Low Countries.

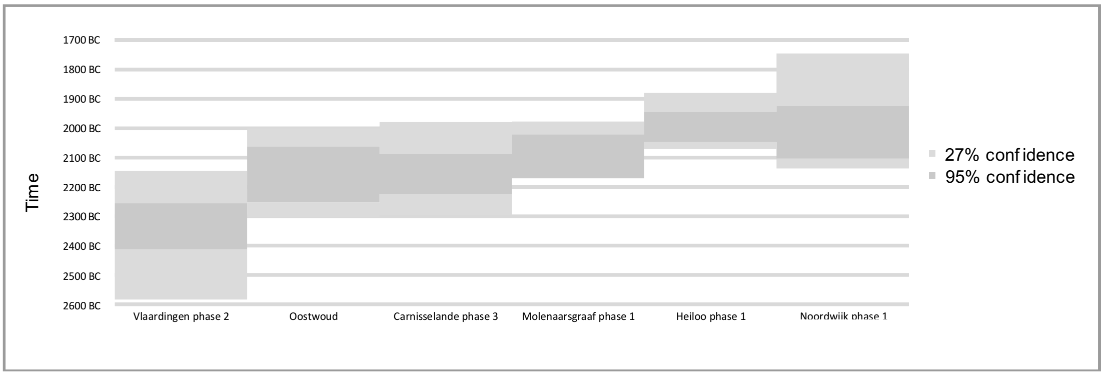

Figure 6. Probability of occupation at several archaeological sites with remains of houses and the arable lands of Oostwoud (Bayesian models are published in Kleijne and Drenth 2019, Fokkens *et al* 2017).

however. These houses continue to show a simple two-aisled plan throughout the 3rd millennium BC, just as the earlier house plans in Oldenburg LA 232, without any modifications or internal structuring, but with the addition of sunken floors. These features are thought to have been used for storage and craft activities (see for instance Revshøjgård: Simonsen 2017).

Between 2600 and 2200 BC, a decrease in settlements and subsistence intensity is also visible from palynological evidence for human impact (Feeser *et al* 2012). From *ca.* 2200 BC onwards, subsistence activities can be characterised as an intensified mixed farming economy (Kirleis 2019, Brozio *et al* 2019a). At both Flintbek LA20 and Archsum LA65, a cultivation soil with plough marks developed during the occupation between 2200 and 1900 BC. More plough marks in Schleswig-Holstein are known from the period between 2000 and 1700 BC, often found below Early Bronze Age burial monuments (*e.g.* Tegtmeier 1993). Mixed cultivation on these arable fields was practiced with both *Hordeum vulgare* and *Triticum dicoccum*. Large quantities of both cereals and chaff remains were found in a pit at Bosau (Kroll 1980, Kirleis *et al* 2012), and human impact also seems to have increased (Feeser *et al* 2019). In addition, the introduction of *Triticum spelta*, a crop resistant to more severe weather, can be dated to this period after 2300 BC in Southern Scandinavia and Central Europe (Akeret 2005, Jacomet 2008, Lechterbeck *et al* 2013,

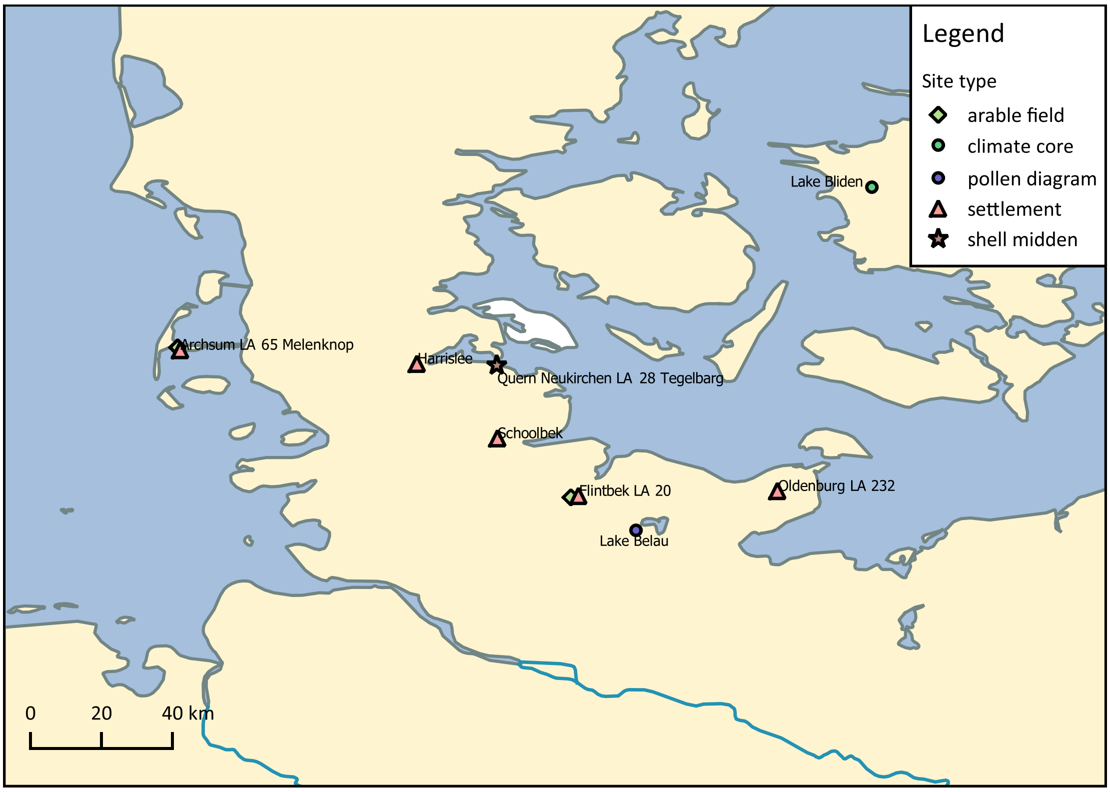

Figure 7. All the mentioned sites in Schleswig-Holstein.

Kleijne 2019, 113–115). This economic intensification and population increase can be associated with the development of new exchange networks, investing in the highly skilled production and the exchange of flint daggers (Brozio *et al* 2019c). A recent paper (Knitter *et al* 2019) models these land-use practices for Eastern Holstein and assumes a similar intensification, without reaching the carrying capacity of the natural landscape. An important exception to this model of agricultural economy intensification is the settlement site of Quern-Neukirchen 'Tegelbarg'. This settlement developed between 2200 and 1900 BC and is identified as a shell-midden (Arnold 1981, Hartz and Müller 2018). This site is characterised by an up to 40 cm thick layer of occupation debris, flint artefact production waste, hearths, and mussel shells. Found within this midden are the remains of gathered wild plants and fruits (Schaller and Kirleis 2018), both wild animals and livestock, and a large number of thrown away shells of mussel (*Mytilus edulis*) and cockle (*Cerastoderma edule*). Fish remains are notably absent (although no sieving was carried out; Höfgen 2018). It is unclear if the shell-midden was a seasonal camp or continuously occupied and how these activities relate to the Late Neolithic arable farming and husbandry economy. Similarly, shell middens dating to the 3rd millennium BC are known from Denmark (Andersen 2007) and the Netherlands (*e.g.* Kleijne *et al* 2013) and might fit into a broader pattern of continued reliance on wild and marine food sources.

With regard to exchange networks, Schleswig-Holstein has some minor evidence for Bell Beaker associated material culture deposited in specific funerary contexts and as loose finds, dating between 2350 and 2000 BC (Kleijne *et al* (accepted)). Another development after 2350 BC is the clear boom in the production and regional exchange of new kinds of objects, in particular flint daggers (Müller 2015, Brozio *et al* 2019c, Kleijne *et al* (accepted)). Bell Beaker pottery of a regional style is occasionally found on settlements, but notably absent from burials (Kleijne *et al* (accepted)). In contrast, undecorated pottery, for example large *Riesenbecher*, is found in graves and as special deposits from the same time onwards (Hartz and Müller 2017). No metal artefacts are known from the later 3rd millennium BC. A depot find near Hamburg contained one of the earliest tin-bronzes in the region, an Emmen-type axe, along with several golden rings and a Barbed Wire decorated pottery vessel, typologically dating around 2000 BC (Vandkilde 2017, Schultrich 2018).

4. Analysis: comparing the socio-cultural parameters of resilience

4.1. Settlement occupation and housebuilding practices

Settlement occupation during the 3rd millennium BC on the Orkney Islands was recently studied by Bayliss *et al* (2017), who indicate that the occupation of many large stone-built structures ends around 2300 BC, after which only several sites with midden deposits remain. This can be interpreted as both a significant drop in population numbers and as a significant change in the building of houses, moving away from the durable, and archaeologically well-visible stone structures.

In the Low Countries, the tradition of wooden two-aisled longhouses continues during the later 3rd millennium BC, but the introduction of new building elements is notable. Some houses exhibit double walls, possibly indicating stalling or other extra wall protection. Other houses have internal four-post structures possibly indicating the presence of above-ground storage facilities. Notable is also the considerable number of repairs carried out by placing new posts near the walls, increasing the durability and use-life of a house (for instance at Noordwijk and Heiloo, see Kleijne and Drenth 2019, figures 16.6 and 16.9).

Similarly, in Schleswig-Holstein, two-aisled longhouses are found from 2200 BC onwards. But here, storage facilities in the form of sunken floors (re-)appear (cf Simonsen 2017, Kleijne *et al* (accepted)).

These changes in housebuilding practices in the Low Countries and in Schleswig-Holstein indicate that while occupation continues and population sizes do not necessarily decrease, housebuilding practices move towards more durable buildings and more indoor storage facilities from 2300/2200 BC onwards. We also observe these changes in housebuilding and food storage practices across continental NW Europe, dating to the same century as the changes in climate, evidenced by a decrease in mean temperatures.

Some elements, such as four-post structures, are already present in structures of the Deule-Escaut and Stein groups predating 2300 BC (see Drenth *et al* 2014, Kleijne and Drenth 2019), which might point to a social explanation for the adoption of this element. As similar changes occur in Unetice Central Europe (*e.g.* Meller *et al* 2019), one can argue for an adoption of this new idea based on a shared ideology. However, both of these arguments are in themselves not sufficient to explain the temporal correlation. In turn, the explanation of resilience of these communities to a climatic change is coherent.

4.2. Subsistence economy

On the Orkney Islands, the subsistence economy during the 3rd millennium BC is primarily based on cattle husbandry and cereal cultivation (Bishop 2015). A special role for some (almost extinct) wild animal species such as deer is seen in several ritual deposits. With the change in settlement occupation, we observe a similar change in subsistence towards less intensive agriculture and possibly a more flexible economy (*e.g.* Dockrill and Bond 2009), supporting a lower population. Models of vegetation development also show that a period of woodland regeneration starts around 2300 BC (Bunting *et al* 2018). The Late Neolithic in the wetland areas of the western Netherlands is characterised by a flexible economy. This practice of an 'extended broad spectrum' subsistence economy (cf. Louwe Kooijmans 1993), in which the exploitation of wild resources is critical, continues also after 2300/2200 BC, with evidence for the use of large fishing weirs (most recently: Hogestijn 2019). In the upland parts of the Netherlands, pastoralism played an important role (Doorenbosch 2013).

A similar flexibility is visible in Schleswig-Holstein in the form of the coastal shell midden at Tegelbarg, where considerable wild resources were extracted (Hartz and Müller 2018) and evidence for agriculture in upland environments was observed. The introduction of spelt wheat (*Triticum spelta*), well-adapted to climatic change due to its hulled seeds, can also be dated to the 2300/2200 BC period in Schleswig-Holstein (Effenberger 2018). Both in Schleswig-Holstein and in the Low Countries, we also see an increase in the frequency of arable fields after 2300 BC, indicating an intensification of agricultural practices (see figure 8).

We argue that the flexible subsistence strategy, whereby many resources are derived from varied sources—both wild and cultivated—is a favourable practice for communities that are then resilient to external forces such as climatic change (but also to the influx of new communities, as Bicho (*et al* 2016) has shown). This leads to better food security, can help communities to withstand harvest failures (cf Hartz and Müller 2018), and also enables risks, which are connected to the intensification of arable farming, to be overcome.

4.3. Exchange networks

Many studies have focused on the cultural affiliation of particular objects from the late 3rd millennium BC in NW Europe with particular types, shapes and combinations of objects being attributed to certain new emerging phenomena. The Bell Beaker phenomenon is the clearest example of this, where particular exotic objects are found together in standardised funerary assemblages (see Introduction).

On the Orkney Islands, the absence of a traditional Bell Beaker funerary ritual and associated pottery or other artefacts is striking. Several pottery vessels have been found that seem to have been inspired by Bell Beaker designs, using a local vessel shape repertoire and less refined decoration techniques (*e.g.* Gibson 1984), signifying only the superficial knowledge of such traditions. The rich burial from the Knowes of Trotty with its elaborate golden and amber artefacts (Sheridan *et al* 2003) and two bronze daggers can be identified as 'Wessex', a style found in rich burials and special objects that are socially and spatially distinct from Bell Beaker, both in the objects themselves and their rich funerary practices, which include

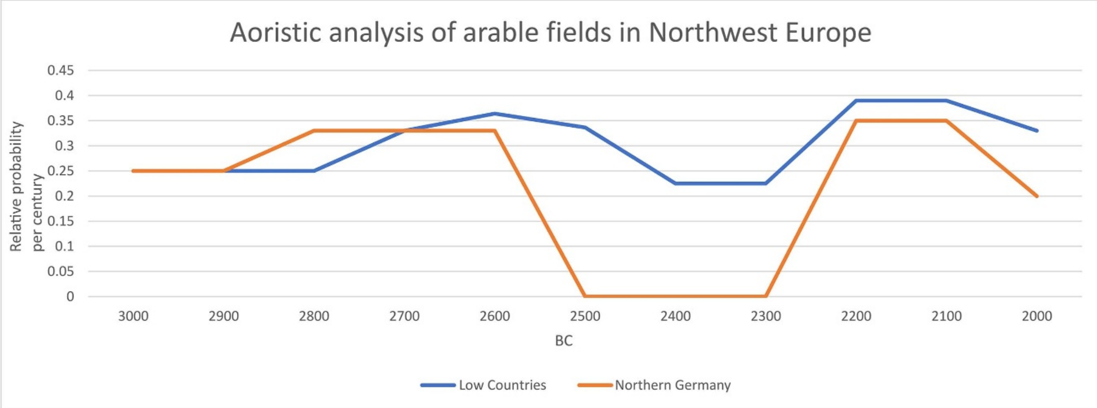

Figure 8. Relative probability of the frequency of arable fields in Northwest Europe (for details concerning the method, see methodology and Mischka 2004).

cremation burials and golden artefacts (Needham 2000, 2005, 2019). It is these Wessex communities and similar elites in Northern France that form the backbone of the *maritory,* which Needham (2009) identifies to describe the exchange of ideas and objects from 2200 BC onwards. This is also signified by the first evidence for large sea-going, sewn-plank boats such as the Dover boat (Vande Noort 2006). During the same period, the exchange of traditional Bell Beaker material culture and ideas is regionalised (termed the 'fission' horizon by Needham 2005), with both burials including more regional objects and pottery developing into more regional styles such as Food Vessels and Collared Urns. On the Orkney Islands, however, none of these latter developments is visible, indicating the separate development of exchange networks here. In the Low Countries, the characteristic practice of constructing graves with artefacts of the 'Bell Beaker' repertoire is still practiced after 2300 BC, with new regionally specific elaborate decoration motifs and vessel types (Veluwe style and Potbeker vessels, respectively; Beckerman 2012, Kleijne 2019). From 2200/2100 BC onwards, an introduction of specific metal and flint artefacts (halberds and daggers), a new metal composition (arsenic copper) and new pottery decoration (Barbed Wire) take place (Fontijn 2002, Kleijne 2019, 78–80). This transpires within a continuing funerary practice in which particular objects (pins, daggers, arrowheads) with long-distance significance are deposited and particular individuals are chosen to be 'dressed in internationality'. This 'internationality' or long-distance character can be based on the traditional Bell Beaker funerary ritual, but can also include new items and ideas such as halberds (Unetice; *e.g.* the Wageningen hoard; Fokkens 2001), cremations with daggers and arrowheads (Wessex; *e.g.* Verhart 2015) or daggers (Scandinavia; *e.g.* Drenth 2015). In Schleswig-Holstein, late Corded Ware (Brozio 2019) and Bell Beaker burials (Kleijne *et al* (accepted)), dating between 2500 and 2350 BC, are found in low quantities. Starting around 2350 BC, the exchange network is dominated by regionally produced flint daggers (see Müller 2015, Brozio 2019, Kleijne *et al* (accepted)), reflecting a move away from long-distance towards a more regionalised focus on Scandinavia in conjunction with regionalised Bell Beaker style pottery found on settlements ('Myrhøj' style; Liversage 2003). The introduction of tin-bronze artefacts and Barbed Wire pottery is found from 2000 BC onwards (Schultrich 2018), and only piecemeal, not necessarily foreboding major changes in exchange networks for another 300 years (see also Iversen 2017). In conclusion, both on the British Isles and in the Low Countries, the development of new (elite) exchange networks is noted after 2200 BC, termed 'Wessex' or associated with new 'international' style objects (early bronzes, gold, faience, jet and amber) from long-distant exchanges. In conjunction, traditional Bell Beaker exchange networks continue to develop into more regional styles of pottery decoration and funerary practices. In Schleswig-Holstein, a similar development takes place with the regionalised development of Bell Beaker ideas, however here connected to a thriving exchange of flint daggers and associated ideas within Scandinavia.

5. Discussion: comparing the socio-cultural parameters for resilience to climate change

In the introductory paragraphs, we defined several parameters for socio-cultural resilience to climate change. These include settlement occupation, house-building practices, food security and exchange networks. In the analysis, we subsequently introduced the archaeological record for the 3rd millennium BC in the three study areas and analysed the study areas based on the defined parameters in both a quantitative and qualitative evaluation. In this discussion, we would like to compare the results from the various parameters with each other for the respective

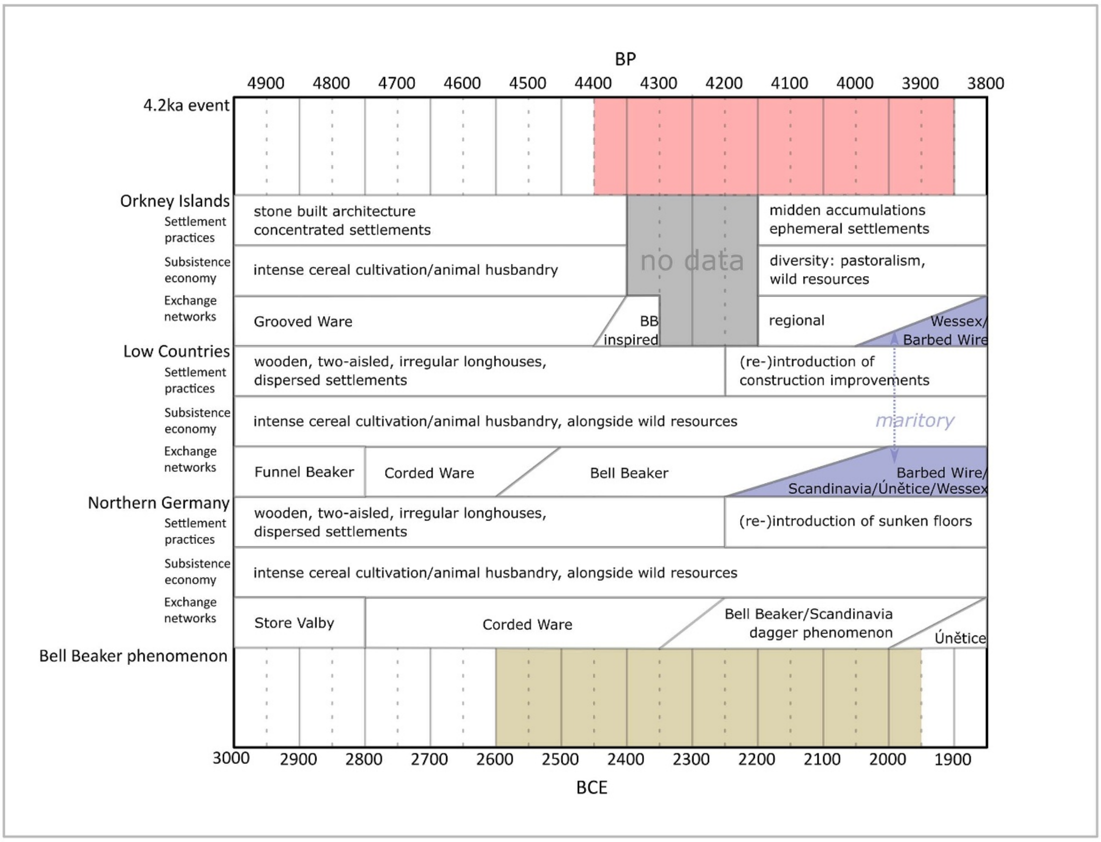

Figure 9. Alignment of the 4.2 ka BP climatic event and regional socio-cultural parameters.

study areas, align them in time (see figure 9), and understand these parameters from the perspective of resilience in relation to the climate changes resulting from the 4.2 ka BP event.

On the Orkney Islands, a decrease in settlement occupation coincides with changes in housebuilding practices, a less intensive shift towards a more flexible subsistence economy, and the localisation of exchange networks, which are visible around 2300 BC. First around 2100 BC, 200 years later, we see the communities becoming part of a new exchange network focusing on Wessex elites and contacts with communities across the British Isles. This latter change is not reflected in the other parameters, but a clear lack of archaeological visibility might (partly) tribute to this. With regard to resilience, the co-occurrence of all these parameters around 2300 BC can best be seen as a combination of social/ideological factors and the 4.2 ka BP event. While the Late Neolithic stone-built structures and associated Grooved Ware exchange mechanisms collapsed due to social and ideological factors (following Clarke *et al* 2016), the absence of large scale settlement occupation from the period after 2300 BC (contrary to other areas of Northern Scotland, which similarly dealt with a Late Neolithic-Chalcolithic ideological transition; see for instance Sharples 2015), can be explained by environmental factors, linking a changing climate to the regrowth of woodland (Bunting *et al* 2018) and the need for a more flexible subsistence economy.

In the Low Countries, we see a continuity in settlement occupation and housebuilding practices, particularly in the Western Netherlands, where there is also most of the evidence for a flexible subsistence economy continuing throughout the Late Neolithic. Modifications of house building and food storage as well as an increase in the number of arable fields all take place from 2300 BC onwards. The exchange of ideas and objects is distinguished by similar continuity, with the influx of new raw materials and objects from Central Europe after 2200 BC, being used and deposited in traditional ways (Fontijn 2002). However, these changes are not concurrent. The changes in housebuilding and the intensification of agriculture predate the influx of the new kinds of materials by at least a century, indicating that the former practices can best be seen as the resilient behaviour of communities during a changing climate, predating the social and ideological changes of Central European origin.

In Schleswig-Holstein, the 4.2 ka BP event seems to have had a different regional effect. Others have argued for the rise of new regional elites and an increase in population sizes after 2350 BC (Brozio 2019), with the production of flint daggers as new status symbols. This is further supported by the number of house plans known (*e.g.* Ethelberg *et al* 2000), contrasting the low population sizes before 2350 BC and the absence of an early Bell Beaker phenomenon in Schleswig-Holstein (Müller 2015, Kleijne *et al* (accepted)). The changes mark a shift from an exchange network focused on the North Sea to a more Baltic and Scandinavian orientation. This new shift and an uptake into the wider world of North West Europe are first visible after 2000 BC. The increase in arable land after 2300 BC, similar to the Low Countries, is another piece of evidence for the resilience of these communities, with a possible colder and dryer climate being more favourable for cereal cultivation, partly associated with the introduction of a new cereal crop species fit for these conditions. Bad harvests were then compensated through wild resources such as shellfish.[2] More intensive agriculture might also have been required to secure output, but it was definitely not limited by climatic or environmental factors in Schleswig-Holstein (Knitter *et al* 2019).

6. Conclusion

The 4.2 ka BP climatic event is generally dated between 2450 and 1900 BC. It has become clear that this climatic event is well visible in marine records, but not always clear in terrestrial records, due to regional variability in both the expression of the phenomenon and in the way it is recorded in climatic proxies. Therefore, it is argued that the impact of this climatic change (generally seen in colder temperatures and higher humidity) was not uniform, but variable across Northwest Europe.

Accordingly, we state that we can gain a better understanding of the socio-cultural changes and the impact of this climatic change across Northwest Europe by using the concept of resilience, focusing on several particular socio-cultural practices.

In order to understand these practices, we reviewed the archaeological evidence. Thereby, we focused on changes in settlement occupation and housebuilding practices, subsistence economy and exchange networks around the southern North Sea. Important first observations include the co-occurrence of a shift in settlement occupation, house building and subsistence practices on the Orkney Islands, with a decrease in the intensity of exchange networks towards an absolute minimum around 2300 BC. Only 200–300 years later, these regional exchanges seem to take form again within the newly formed 'Wessex' tradition of a North Sea *maritory*, significantly different from the preceding Bell Beaker phenomenon.

Interestingly, we have determined that the Continental record for both the Low Countries and Schleswig-Holstein shows continuity in settlement, subsistence and house building practices, with several changes in house building styles. In the Low Countries, exchange networks display a regionalisation around 2300 BC, but long-distance exchanges connect communities to both the North Sea *maritory* and the Unetice heartland after 2200 BC. In Schleswig-Holstein, these developments are absent as a consequence of the strongly divergent exchange network focusing on Scandinavia from 2300 BC onwards.

The different perspective taken in this paper, focusing on the role that resilience to climate change played at the end of the third millennium BC, contrasts to the work previously done on the late 3rd millennium BC in Northwest Europe. As such, this perspective has led to several new insights. We studied datasets that were previously never quantified, combined, and compared. Such analyses have proven to be worthwhile, given their dependent relationships and the outcomes of this study. Moreover, our comparison of archaeological parameters for socio-cultural change and climatological parameters on a regional level has opened up the possibilities of further interregional studies. Future work should focus on improving the regional signals for climatic change and getting a better grip on human practices from an archaeological perspective.

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Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

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[2] A similar development in arable fields is visible for the Scottish Western Isles, where an increase in plough marks and settlement sites postdates 2300 BC (Sharples 2009).

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