Research Paper

The Holocene
2019, Vol. 29(11) 1782–1800
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DOI: 10.1177/0959683619862036
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Convergent catastrophes and the termination of the Arctic Norwegian Stone Age: A multi-proxy assessment of the demographic and adaptive responses of mid-Holocene collectors to biophysical forcing

Erlend Kirkeng Jørgensen[1] and Felix Riede[2]

Abstract

Using multiple archeological and paleoenvironmental proxies, this paper makes the case for a climate-induced convergent catastrophe among the human population of terminal Stone Age Arctic Norway. We show that climatic changes correlate with the termination of the so-called *Gressbakken phase* (4200–3500 cal BP), and unpack the middle-range mechanisms linking the Gressbakken termination to contemporaneous changes in the biophysical environment. We show that what was a Holocene extreme, and likely volcanically-induced, climate deterioration around 3550 cal BP coincided with a population decline as reflected in the frequency of radiocarbon-dated archeological sites along with major changes in material culture and settlement pattern. Together, these proxies suggest a return to forms of social and economic organization based on lower population densities, higher residential mobility, and reduced locational investments. In establishing the middle-range ecological mechanics mediating these changes into archeologically observable patterns, the results indicate that the Gressbakken termination was the result of a particularly unstable climate period characterized by regional paludification, increased effective precipitation, forest decline, and likely impacts on reindeer populations and their migratory behavior, with drastic human implications. We argue for a convergent catastrophe-scenario in which a series of hardships between 4000 and 3500 cal BP exceeded the adaptive mitigation capabilities of the contemporaneous Arctic Norwegian population. Our study supports the notion that increased sedentism and locational investment actually increases vulnerability in the face of rapid biophysical change and contributes to the growing database of past human ecodynamics that speak to current socio-ecological concerns.

Keywords

adaptive strategies, Arctic Norway, climate forcing, Gressbakken phase, human ecodynamics, palaeodemography, resilience, risk mitigation, tephrochronology

Received 29 January 2019; revised manuscript accepted 25 May 2019

Introduction

The societal impacts of past climatic and environmental changes and events – and the implications of these for future trajectories of social change (e.g. Costanza et al., 2007) – have been in the limelight of recent research (Butzer, 2012; Cooper and Sheets, 2012; Middleton, 2017; Weiss and Bradley, 2001). Although controversy persists, much of this research suggests that past environmental changes frequently precipitated societal 'moments of crisis' (Tipping et al., 2012: 9). Within this line of investigation, recent high-resolution paleoclimatic data and modeling have revealed that volcanic forcing of climatic variability led to important downstream cultural changes in the state-level societies of the 6th and subsequent centuries CE across Europe (Büntgen et al., 2016; Toohey et al., 2016). Analyses comparing different archeological and climatic proxies indicate complex and substantive causal pathways connecting distant volcanic eruptions, temperature changes, and societal consequences including economic, political, and religious transformations (Gräslund and Price, 2012; Høilund Nielsen, 2005; Loveluck et al., 2018; Nordvig and Riede, 2018; Price and Gräslund, 2015). Parallel to this focus on the decline and collapse – however defined (cf. Middleton, 2017) – of complex societies, major research efforts have also been invested in elucidating the impact of climate shifts and ecosystem restructuration on various Holocene hunter-gatherer populations (Robinson and Riede, 2018).

Given an exceptionally well-curated and well-researched archeological record combined with an abundance of paleoenvironmental proxies, it has been suggested that northern Europe is 'an extraordinary laboratory for the investigation of human colonization and adaptation' (Price, 1991: 185). Despite such programmatic claims, the archeological record of Northern Norway

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[1]Department of Archaeology, History, Religious Studies and Theology, UiT – The Arctic University of Norway, Norway
[2]Laboratory for Past Disaster Science, Department of Archaeology and Heritage Studies, Aarhus University, Denmark

Corresponding author:
Erlend Kirkeng Jørgensen, Department of Archaeology, History, Religious Studies and Theology, UiT – The Arctic University of Norway, Postbox 6050 Langnes, 9037 Tromsø, Norway.
Email: erlend.k.jorgensen@uit.no

has not been interrogated in any depth with regard to such past impacts and their human responses. Located well above the Arctic Circle, northern Norwegian environments are comparatively harsh and human population densities low, as clearly indicated by population estimates based on historic census data (Hansen, 2009; Hood, 2015). Traditionally, however, the population history of prehistoric Arctic Norway has mostly been assumed to be continuous, with internal development being the main driver of change. This has recently been challenged by palaeodemographic modeling suggesting several marked boom and bust cycles (Jørgensen, 2018), raising the pressing question of what possible causes may stand behind these population dynamics. This is particularly pertinent when considering that one such cycle corresponds to the iconic *Gressbakken phase*. Traditionally dated to 4200–3800 cal BP, it has become iconic through the rich archeological record found across northernmost Fennoscandia and northwestern Russia, including large semi-subterranean houses, substantial refuse middens, and a rich and diverse osseous industry. Against the background of this material effervescence, the extensively investigated *Gressbakken phase* is thought to reflect heightened levels of sedentism and greater population size and density, followed by a radical reduction in those demographic parameters along with its termination. These factors make the *Gressbakken phase* uniquely interesting, as they allow testing of more generalized anthropological models for the explanation of cultural change, risk-management, and adaptive strategies among hunter-gatherers. We present a first, rigorous dating scheme of the *Gressbakken phase* based on a compilation of all existing, directly dated Gressbakken houses. As the termination was seemingly dramatic and wide-spread, we here review the possible impacts of abrupt and persistent climate forcing on what has been termed the most socially complex hunter-gatherers of North Norwegian prehistory (Schanche, 1994: 181). Previous portrayals of the Gressbakken termination have emphasized a move from complex semi-sedentary groups to smaller and mobile units, suggesting that increasing social stress following inequality eventually brought about this 'collapse' (Myrvoll, 1992: 183; Olsen, 1994: 131; Schanche, 1988, 1994). Importantly, the alleged complexity of the *Gressbakken phase* and its decline allows for a local test of the hypothesized reduction in resilience following increased societal complexity, reduced residential mobility, and locational investment, as originally formulated by Sheets (2001, 2012). The recent accumulation of local and highly resolved climate proxy data of direct relevance to human socio-ecological issues enables us to make a systematic review of the environmental setting of the *Gressbakken phase* and to better evaluate hypotheses of potential climate-induced demographic and social change. Interestingly, previous studies have placed substantial emphasis on the Gressbakken phenomenon as a canvas for interpretations concerning symbolism and social complexity, side-lining the importance of environmental factors in cultural change (Hood, 2019b: 21; Olsen, 1994; Schanche, 1994). It is therefore all the more important to investigate afresh the human ecodynamics pertaining to the *Gressbakken phase*. Here, we attempt such an investigation by compiling the first comprehensive radiocarbon record for the *Gressbakken phase*, and by analyzing this database as a first-pass proxy for human population activity. This demographic proxy is then judiciously combined with highly resolved climatic proxies as well as material culture evidence. We show that significant reductions in human presence correlate with similarly significant climatic and environmental perturbations and, as a consequence, with cultural changes. Against the background of these observations, we evaluate what mechanisms may account for the demographic dynamics around 3550 cal BP and thus contribute to a wider anthropological and human ecodynamic research agenda on human adaptive responses, risk-mitigation strategies, and past disaster science. Based on the present ecodynamic review, we also suggest a revision of the established chronology for the *Gressbakken phase*, proposing a new terminal date at 3500 cal BP – relating to regional environmental perturbations as well as continental-scale environmental and cultural upheavals.

The *Gressbakken phase*: Background and framing

The *Gressbakken phase*, named after the eponymous site in the Varanger Fjord (eastern Finnmark), is one of the most thoroughly investigated phenomena of North Norwegian prehistory. It has formally been defined as a spatiotemporal *phase*, on the basis of its distinct cultural horizon in the Northern Fennoscandian archeological sequence (Hood, 2016). Most *Gressbakken phase* sites are coastal cluster sites of multiple dwelling structures organized in rows, and are generally characterized by relatively rich material, including extensive refuse middens, semi-subterranean houses of substantial size, osseous tools and, more rarely, human remains. Chronologically, the Gressbakken phenomenon constitutes the final phase of the Younger Stone Age of Northern Norway, at the onset of the early Metal Period. It is traditionally dated to 4200–3800 cal BP (Helskog, 1980, 1984; Olsen, 1994: 72; Schanche, 1995: 181).

We here focus on the *Gressbakken phase* as a tradition with particular emphasis on housing structures – in line with the common use of houses as a primary criterion for defining the period as a distinct horizon in the archeological record (cf. Simonsen, 1979). Gressbakken houses have been defined as a typologically distinct tradition, based on morphological and architectural features listed in Table 1 and some of which are illustrated in Figure 1. The previously derived and still highly influential typology of changes in house-building throughout the Younger Stone Age of Northern Norway is presented in Table 1. However, current data suggest underappreciated variation in house types. For example, it has been demonstrated that a variety of both the assumed later Mortensnes and earlier Nyelv houses were used throughout the *Gressbakken phase* (Niemi and Oppvang, 2018; Oppvang, 2018).

The *Gressbakken phase* house phenomenon has been portrayed as particular to eastern Finnmark (Simonsen, 1996: 124), based on the observation of on average larger house-floors (30 m^2) and more numerous, row-organized houses, compared to the smaller (20 m^2) and mostly minor house-clusters in western Finnmark (Damm et al., 2019). Nonetheless, similarities across Finnmark have been pointed to on various occasions (Andreassen, 1985: 145; Schanche, 1994: 58; Simonsen, 1996: 130). Data accumulated since the early 1990s seem to cement the picture of shared trends across Finnmark during this period, consisting of increasing settlement sizes, richer finds, larger and more deeply dug pit houses with two hearths and, in some instances, annexes. Cognizant of potential micro-regional variability, we here apply the term *Gressbakken phase* to include all of Finnmark. We believe this is justified due to the identification of similar sites outside the core area of Varanger, both on the Russian Kola Peninsula (east), in Porsanger (central Finnmark), and at Sørøya (western Finnmark). Previous syntheses have remarked upon the comparable developments also in western Finnmark (increased house sizes, double hearths, rich inventories), but have been reluctant to classify the trends outside the Varanger Fjord area as part of the *Gressbakken phase* owing to the lack of other diagnostic morphological house features (Olsen, 1994: 75; cf. Andreassen, 1985). Such cases are now known from western Finnmark, such as the Tollevika site in Alta (Bell, 2004), as well as at Slettnes VC (Hesjedal et al., 1996: 136).

Outside Finnmark County, the 4200–3800 cal BP interval is less well investigated. Different geomorphological conditions

Table 1. Traditional typology of Younger Stone Age houses in Northern Norway.

Traditional house typology of Younger Stone Age Northern Norway (primarily eastern Finnmark)

House type	Assumed age span, cal BP	Characteristics	Key references
Karlebotn type	6500–5000	Small, round houses of slight subterranean excavation, with one central hearth and no marked entrances.	Simonsen (1979: 367)
Nyelv type	5200–4500	Medium-sized, rectangular, and slightly excavated floor plan with two central hearths separated by cooking-stones, and without marked entrances.	Olsen (1994: 71) and Simonsen (1979: 375)
Gressbakken type	4500–3800	Large, rectangular, and deeply excavated floor plan, with two central and symmetrical hearths separated by cooking-stones. Large middens and wall embankments, as well as multiple entrances and annexes.	Schanche (1994) and Simonsen (1961)
Mortensnes type	3800–3000	Medium-sized, square (sub-rectangular), and deeply excavated floor plan, with one asymmetrically positioned hearth and lacking marked entrances.	Johansen and Odner (1968), Olsen (1994: 113), and Schanche (1988: 131)

Figure 1. (a) Satellite photo of the Gressbakken type site and its position on top of a glaciofluvial delta (from GeoNorge.no). (b) Original photo of House 3 under excavation, from Simonsen (1961: 127), digital remastering by Sveinulf Hegstad at Tromsø Museum. (c) Plan drawing of House 3, from Hood and Melsæther (2016). Reproduced with permission.

may be partly responsible, as the preservation and discovery of *Gressbakken* sites becomes less likely outside the Varanger Fjord – as its sheltered and lower energy environs are more suitable for sedimentary deposition when compared to central and western coastal Northern Norway, as demonstrated in Figure 1. Large, *Gressbakken*-like houses with similar diagnostic architectural features have been identified on favorable geomorphological sites in western Finnmark, for example, Båtnes and Hanselv. This is in addition to previously known and partly investigated sites at both Sørøya island in western Finnmark, such as at Slettnes, Sandbukt, Risvåg, and Markeila (Simonsen, 1964), and the Porsanger Fjord area in central coastal Finnmark (Oppvang et al., 2018; Schanche, 1994: 59).

It has previously been asserted that significant and widespread changes correlated with the disappearance of the classic *Gressbakken* houses, such as increased residential mobility, an economic restructuration toward terrestrial resource exploitation, mainly to maintain trading networks toward the east in exchange for metal products, major changes in rock art depictions resembling Southern Scandinavian Bronze Age motifs, and a markedly less ornate material culture compared with the *Gressbakken phase* (Myrvoll, 1992; Olsen, 1994: 127–129). Yet, no coherent and testable hypothesis for what may have caused these dramatic changes has so far been offered.

Complex collectors during the Gressbakken phase – Predictions for socio-ecological resilience

Following Binford (1980), hunter-gatherers can be placed somewhere along a forager-to-collector spectrum, where the collector-end is characterized by large and often quasi-sedentary groups, complex social structures, investment into tended and untended

Figure 2. Selection of semi-diagnostic object classes from the Gressbakken phase. All objects stem from the classic Gressbakken site, House 4 (Ts5526). (a) From upper left to lower right: 1. Bone comb (hx); 2. Bone projectile point (kn); 3. Bone needle (ct); 4. Fish hook, rounded base and straight, perforated attachment head (hc); 5. Fish hook, angled base and transverse attachment head (bæ); 6. Fish line davit block (hs); 7. Miniature, oblong slate chisel (ge); 8. Small, fluted slate arrowhead of the Sunderøy type (dz); 9. Miniature slate knife (bo); 10. Perforated dog/fox tooth pendant (if); 11. Bone beads, still attached (is); 12. Asymmetric, line and dot ornamented bone piece, representative of much ornamented bone industry (iv); and 13. Ornamented bone plate, potential ulu-like artifact (hø). (b) Ts5525ds ornamented bone comb. (c) Ts5526ak harpoon. Photo by Mari Karlstad, Tromsø Museum.

facilities, often exotic goods and raw materials, and sometimes social differentiation and higher population densities (Kelly, 2013). Such collector-like socio-economic constellations emerge in ecological settings offering concentrated and more or less predictable resources.

The issue of social complexity has long been debated with respect to the *Gressbakken phase*, with strong emphasis being put on the collector-like properties in evidence. The often spectacular and well-preserved archeological features and artifacts associated with the *Gressbakken phase* (Figure 2) have resulted in extensive archeological investigations (Nummedal, 1937; Schanche, 1994; Simonsen, 1961), as well as analyses of the otherwise very rare faunal data (Hodgetts, 2010; Renouf, 1984, 1989), midden deposits (Helama and Hood, 2011; Hood and Helama, 2010; Hood and Melsæther, 2016) and their geoarcheological preservative properties (Martens et al., 2017). These factors have been used to argue that the *Gressbakken phase* marked the heyday of social complexity within the Stone Age of Northern Norway. The characteristics used to define the *Gressbakken phase* as distinctly more complex than both the preceding as well as the following phases are summarized in Table 2. *Gressbakken phase* sites have been interpreted as representing large and hierarchically organized Stone Age communities that are at least semi-sedentary, with substantial cooperation in the context of large marine mammal exploitation. They are most commonly framed in direct analogy to the American Coast Salish (Schanche, 1995: 184; cf. Angelbeck, 2016; Drucker, 1951; Gronenborn, 2003; Suttles and Sturtevant, 1990). Olsen (1994: 91; following Renouf, 1989), for instance, suggested that the presence of whale and Delphinidae bones in some middens together with the (assumed) increase in settlement size and increasing number of dwelling structures at each site during the *Gressbakken phase* could be a corollary of whale hunting requiring the careful coordination of group labor.

Critics, however, have suggested that the case for social complexity in Northern Norway has been overstated (Hood, 1995, 2019b). This is partly a consequence of high-precision re-dating of elements fundamental to the interpretation of the *Gressbakken phase* as particularly complex; this work has resulted in copper implements, late comb ceramics, anthropomorphic figurines, and ornamented osseous tools now being shifted back to 5000 cal BP (Hood and Helama, 2010). The *Gressbakken phase* may therefore be more of a culmination of longer term developments than a short-term fluorescence. Regardless of material culture trends, regional demographic modeling suggests a distinct population growth cycle that corresponds to the *Gressbakken phase* (Jørgensen, 2018). The mechanisms responsible for this event have yet to be fully explored.

The *Gressbakken phase* has furthermore been presented as being of local origin and its emergence and development primarily driven by internal social dynamics (Schanche, 1994: 207–208). A systematic attempt at regional contextualization clearly indicates, however, that the core area of the house tradition is, in fact, situated in Northwestern Russia (Hood, 2019b: 148). Large-scale field surveys of the Kola Peninsula have identified a large number of house pits morphologically identical to those of the Norwegian *Gressbakken phase*, and with corresponding material culture (Kolpakov and Murashkin, 2016). The few existing dates from *Gressbakken*-like houses on the Kola Peninsula confirm a correspondence with the *Gressbakken phase* elsewhere (Helskog et al., in press; Hood, 2019b: 151). The assumed variation in house types and settlement pattern along an east–west gradient in Finnmark may therefore result from a clinal distribution of the Gressbakken phenomenon, as is to be expected with increased distance from a core area in Russia. In sum, the Gressbakken phenomenon appears to have developed first outside of Northern Norway and to have developed over a longer period than previously assumed. Its termination, however, stands out as abrupt and comprehensive.

Against the canvas of current data, we shy away from strictly viewing the *Gressbakken phase* as reflecting ‘complex’ hunter-gatherers on par with classic analogs of the ethnographic present. Still, we remain confident in attributing to it higher population size and density, near-sedentism, and increased investments in tended and untended facilities, thus meeting some of the requirements traditionally listed in favor of complexity among northern maritime foragers (cf. Rowley-Conwy and Piper, 2016). Although

Table 2. Often-cited indicators of heightened complexity during the Gressbakken phase.

No.	Complexity indicators Characteristic	Key references
1	Large communal sites occupied by a large population (estimated 200 per larger site)	Schanche (1994: 177, 1995: 183), cf. Helskog (1984)
2	Sedentism or near-sedentism	Olsen (1994: 85) and Schanche (1995: 181), cf. Engelstad (1984)
3	Hierarchical social organization	Olsen (1994: 92) and Schanche (1988: 188, 1989, 1995), cf. Simonsen (1972: 164)
4	Economic intensification	Renouf (1989: 191), cf. Hodgetts (2010)
5	Deeply excavated (<1.3 m), semi-subterranean houses of substantial size (average 25 m^2, max < 70 m^2)	Simonsen (1979: 371), cf. Engelstad (1985: 83) and Hood (2019b: 8)
6	Midden accumulation	Hodgetts (2010) and Renouf (1988)
7	Houses organized in rows	Schanche (1994: 72) and Simonsen (1961)
8	Architectural features of houses such as multiple entrances and annexes	Schanche (1995: 180) and Simonsen (1961, 1979), cf. Engelstad (1985: 83, 1988)
9	Mostly two large, stone-lined, symmetrical fireplaces separated by a mid-section often densely packed with fire-cracked rocks	Schanche (1994) and Simonsen (1961, 1979: 171)
10	Burials in cairns and middens. Total of 11 individuals at original Gressbakken site.	Henriksen (2003) and Olsen (1994: 88)
11	Increased ornamentation of osseus industry	Olsen (1994: 90) and Myrvoll (1992)
12	Increase in exotic and prestigious imports (copper from the east, flint artifacts from the south or east)	Olsen (1994: 125)
13	Ritual intensification reflected in anthropomorphic figurines and other ritual paraphernalia	Olsen (1994: 89) and Schanche (1994: 184, 1998)

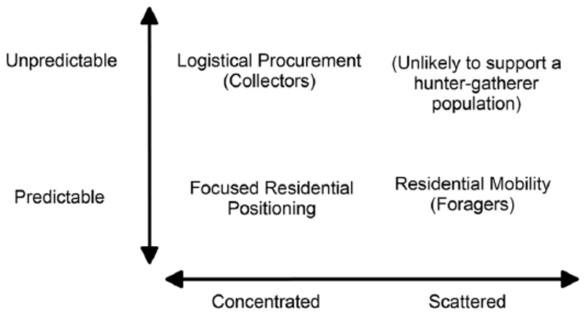

Figure 3. Expected hunter-gatherer mobility strategies in relation to selected resource distribution characteristics. Redrawn from Whallon (2006: 260).

increased social complexity often follows from such demographic conditions, we are not able to empirically demonstrate such complexity (cf. Hawkes, 1954). Nonetheless, we suggest that a number of specific albeit not unique properties of the *Gressbakken phase* mark it as some way toward the collector-end of the adaptive spectrum (cf. Keeley, 1988).

How, then, should we understand the seemingly sudden changes at the termination of the *Gressbakken phase* occurring across the spectrum of economy, settlement pattern, architecture, and material culture – all with attendant implications for time-scheduling, knowledge transmission, mobility, fertility and their demographic corollaries? Whallon (2006) has presented a useful if static matrix within which forager societies can broadly be placed (Figure 3). Their economic organization references the spatiotemporal distribution and predictability of key resources. As a result of substantial climate change and redistribution of biogeography, forager populations are forced toward other forms of social and economic organization. Of crucial importance here is the prediction by resilience theory that increased locational investments and higher degrees of sedentism – the hallmarks of collector systems – would result in reduced resilience in the face of environmental perturbations. Multiple studies report findings in accord with these predictions (Fitzhugh, 2012; Fitzhugh et al., 2016; Redman and Kinzig, 2003; Sheets, 2001). If, then, the *Gressbakken phase* did exhibit such collector-like qualities, it may arguably have been susceptible to environmental stressors, especially if multiple and difficult-to-predict stressors compounded each other, resulting in what Moseley (1999: 59) termed a ‘convergent catastrophe’.

Related to the Whallon model, Halstead and O’Shea (1989) predicted a set of risk-mitigation strategies employed by hunter-gatherers forced further along either the X or Y axis by environmental stressors: economic diversification, increased residential mobility, storage and mass processing of bulk resources, as well as exchange networks and reciprocal social relations with populations reliant on different resources. The archeological effects of such mitigation strategies, as observed for the Gressbakken termination, are reviewed in the discussion.

Materials and methods

Palaeodemography

Since the suggestion that radiocarbon dates can be used as a population proxy (Haynes, 1969; Holdaway and Porch, 1995; Kirch, 1980; Rick, 1987), considerable efforts have been spent on corroborating, criticizing, and qualifying this approach (Contreras and Meadows, 2014; Surovell and Brantingham, 2007; Surovell et al., 2009; Williams, 2012). We here follow Edinborough et al. (2017) in accepting the general usefulness of this methodology for highlighting significant palaeodemographic fluctuations. More specifically with regard to Northern Europe, it has been argued that foragers as well as farmers underwent considerable demographic fluctuations and that these often coincided with climatic or environmental changes (Riede, 2009a, 2009b; Shennan and Edinborough, 2007; Tallavaara and Seppä, 2012; Tallavaara et al., 2010) or, as Tipping et al. (2012) put it, ‘moments of crisis’. Drawing on Binford (2001), we argue that climate affects net productivity and hence carrying capacity, which in turn structures

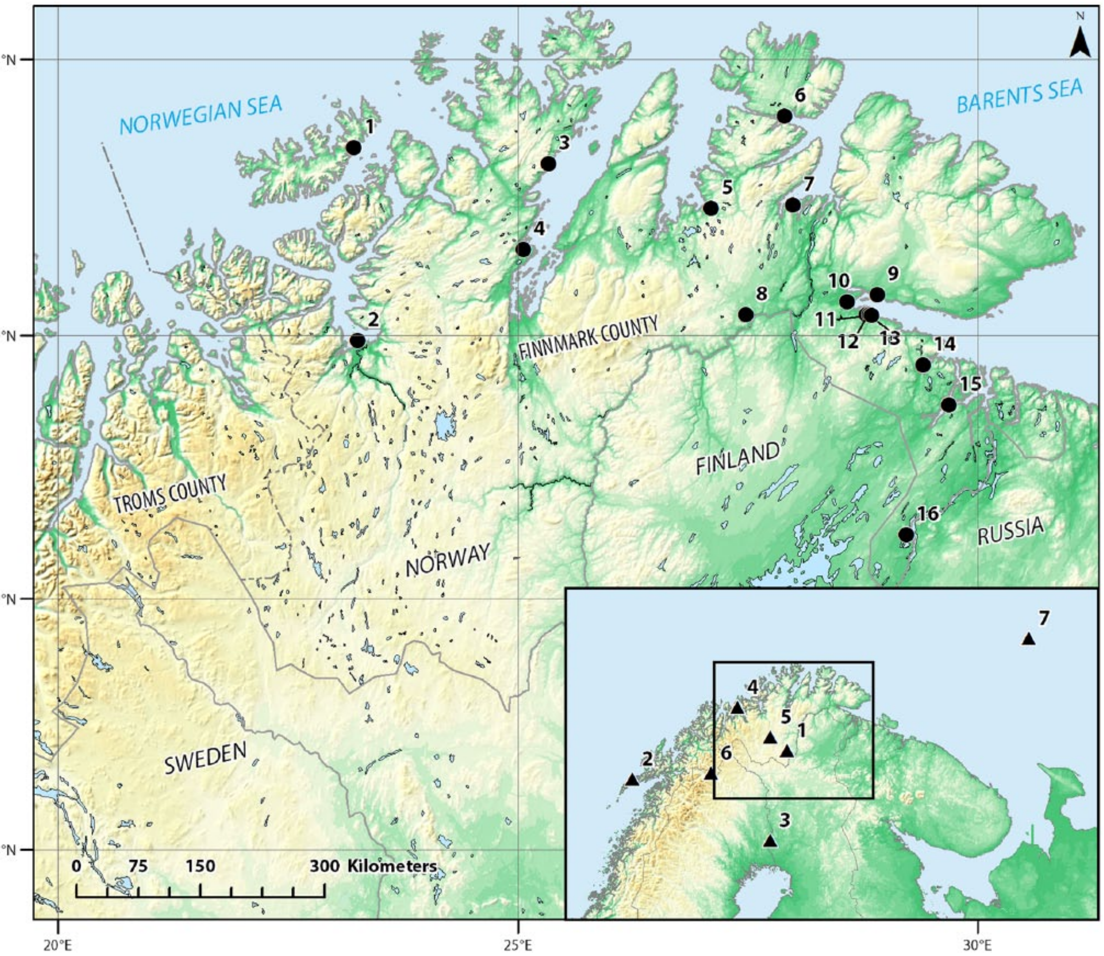

Figure 4. Area map plotting the location of the dated Gressbakken sites, providing data in this paper: 1. Sandbukt, 2. Tollevika, 3. Skarvbergvka, 4. Tverrnes, 5. Leirpollen, 6. Iversfjord, 7. Torhop, 8. Laksjohka, 9. Bergeby, 10. Karlebotn, 11. Advik, 12. Gressbakken, 13. Nyelv, 14. Valen, 15. Kalkkilebukt, and 16. Storsteinneset. Many more Gressbakken sites are known, yet lack direct dates and are thus excluded from the map. The small inset map demonstrates the location of climate proxies discussed in this paper; numbers correspond to their description in Table 3. Basemap data: ESRI, Geodatastyrelsen, The Norwegian Mapping Authority, The National Land Survey of Finland, and Airbus Defence and Space GmbH. Map by Johan Eilertsen Arntzen, UiT.

life-history decisions. Cumulatively, such decisions result in specific demographic patterns. With all the caveats of preservation and research bias in mind, we here present a radiocarbon date proxy record for palaeodemographic changes in Northern Norway for the period covering the *Gressbakken phase*.

For the specific purpose of investigating the occupation intensity of typologically distinct *Gressbakken* sites, we present the first rigorous dating scheme for the *Gressbakken phase* (see SI for radiocarbon data and site information, available online). The dates (n = 107, combined into 74 bins) were collected from 58 directly dated *Gressbakken* houses exhibiting typical morphological traits from across Finnmark County (Figure 4). They were then modeled as a summed probability distribution (SPD), following the procedure described in Dye and Komori (1992), Grove (2011), Ramsey (2017), and Williams (2012).

The data used for the regional, demographic background models are based on the North Norwegian Radiocarbon Record, of which the main results have already been presented elsewhere (Jørgensen, 2018). In order to explore any potential variation on settlement pattern as a response to the *Gressbakken* termination, we also modeled inland population presences on the basis of n = 115 dates, combined into 88 bins of 200-year intervals in order to normalize the effect of overrepresented sites. Dates obtained from pit-fall features are excluded, both as they provide inherently unreliable results and because they do not track habitation activity – which is the matter at hand. The inland area has been significantly less densely investigated, but is included in an attempt to capture settlement dynamics across the region.

All analyses were performed using the Rcarbon package in the R software environment (Bevan and Crema, 2018; R Development Core Team, 2015). Monte-Carlo simulation tests (Shennan, 2013; Timpson et al., 2014) were performed for both background models, as they contribute new (inland model) or minor revisions (regional model) of previously published models (Jørgensen, 2018) following data revision and methodological development. The results of which can be viewed in the SI (available online).

Paleoenvironment

In order to evaluate the environmental setting of the *Gressbakken phase*, we assembled a diverse suite of relevant mid-to-late-Holocene climate proxy records covering the time frame of 6000–2000 cal BP (Table 3). It has already been demonstrated that general northern hemispheric climate reconstructions based exclusively on Greenlandic ice-cores are of less relevance to the climate development in our study area than previously believed due to opposite effects of the North Atlantic Oscillation (Berben et al., 2017; Dawson et al., 2003; Hurrell, 1995; Perner et al., 2015). It is therefore vital that high-resolution and multi-scalar climate data reflecting local-to-regional-scale changes are employed when the aim is to juxtapose these to human demographic and technological responses. Fortunately, Northern Fennoscandia is

Table 3. Climate records employed for paleoenvironmental review.

No.	Site	Core name	General location	Latitude (°)	Longitude (°)	Elevation (m a.s.l.)	Source	Proxy	Resolution mean (year)	Function in climate review	Citation
1	Lapland, regional	Lapland	N Fennoscandia	69.0	25.0	–	Tree	Ring width	1	High-resolution, regional terrestrial baseline	Helama et al. (2010)
2	Rystad	Rystad 1	N Norway	68.24	13.78	40	Peat	Humification index	30	Indicator of temperature and precipitation combined – evapotranspiration – in the outermost western coast	Vorren et al. (2012)
3	Northern Europe, regional	Multiple	N Europe	57–70	8–35	–	Lake	Pollen	–	Stacked summary pollen-based temperature variability record from 36 sites. Provides overall terrestrial climate and vegetation response across N Europe	Seppä et al. (2009)
4	Langfjordjøkelen	Jøp-112	N Norway	70.1	21.42	156	Lake	Titanium, counts per second	< 10	Tracks glacial dynamics in the coastal region of Northern Norway	Wittmeier et al. (2015)
5	Jervtjern	JRT	N Norway	68.4	19.5	548	Lake	Pollen and modeling	67	Relative changes in the upper altitudinal limit of the pine forest, mapped against current levels	Sjögren et al. (2015) and Jensen and Vorren (2008)
6	N Fennoscandia, regional	Multiple	N Norway	68–70	20–30	–	Lake	Pollen	–	Compilation of 59 pollen cores across N Fennoscandia, tracking vegetation changes across inland-coast, east–west axes	Sjögren and Damm (2019) and Damm et al. (2019)
7	Barents Sea	PL-96-112 BC	Barents Sea	71.74	42.61	−286	Marine	Dinocysts	149	Combined measures of marine bioproductivity and sea-ice dynamics in the Barents Sea	Voronina et al. (2001) and De Vernal et al. (2013)

Note that for proxy 1: Moving average smoothing (50 years) was applied to raw data of annual resolution for visualization purposes. Magnitude of temperature variation is therefore less substantial. Please consult original data for realistic annual temperature reconstructions.

Table 4. Identified tephras and other proxies of volcanic impacts in Northern Norway.

Site	Site type	Sample no.	Associated peat median age, cal BP (1950)	Volcanic source	Known age of identified event, cal BP (1950)	Reference
Tønsnes	Bog near archeological site	TØ---12---B 358	6900	Lairg-A	6900	Balascio and Anderson (2016)
Borge	Peatland	–	6900	Lairg-A	6900	Pilcher et al. (2005)
Sellevollmyra	Peatland	SEL-10	6735	Lairg-A	6900	Vorren et al. (2007)
Borge	Peatland	QUB-601/G1: Borge unknown 22	6650	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-601/G2: Borge unknown 23	6650	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-600/G1: Borge unknown 20	6370	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-600/G2: Borge unknown 21	6370	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-598/G1: Borge unknown 16	5800	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-598/G3: Borge unknown 17	5800	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-598/G5: Borge unknown 18	5800	–	–	Pilcher et al. (2005)
Sellevollmyra	Peatland	SEL-9	5771	–	–	Vorren et al. (2007)
Sellevollmyra	Peatland	SEL-8	5667	–	–	Vorren et al. (2007)
Lapland dendro	Dendrochronology	–	4800	–	4800	Helama et al. (2013)
Sellevollmyra	Peatland	SEL-7	4662	–	–	Vorren et al. (2007)
Lapland dendro	Dendrochronology	–	4514	–	4514	Helama et al. (2013)
Bødalsvatnet	Lake	Lower sample	4287	Hekla-4	4260	Pilcher et al. (2005)
Borge	Peatland	–	4287	Hekla-4	4260	Pilcher et al. (2005)
Tønsnes	Bog near archeological site	TØ---12---B 230	4260	Hekla-4	4260	Balascio and Anderson (2016)
Sellevollmyra	Peatland	SEL-6	4120	Hekla-4	4260	Vorren et al. (2007)
Sellevollmyra	Peatland	SEL-5	3821	Kebister?	3750	Vorren et al. (2007)

(Continued)

Table 4. (Continued)

Site	Site type	Sample no.	Associated peat median age, cal BP (1950)	Volcanic source	Known age of identified event, cal BP (1950)	Reference
Lapland dendro	Dendrochronology	–	3534	Thera?	3534	Helama et al. (2013)
Lapland dendro	Dendrochronology	–	3529	Thera?	3529	Helama et al. (2013)
Lapland dendro	Dendrochronology	–	3414	Thera?	3414	Helama et al. (2013)
Lapland dendro	Dendrochronology	–	3403	Thera?	3403	Helama et al. (2013)
Sellevollmyra	Peatland	SEL-4	3123	Hekla-3	3000	Vorren et al. (2007)
Lapland dendro	Dendrochronology	–	2824	–	2824	Helama et al. (2013)
Lapland dendro	Dendrochronology	–	2280	–	2280	Helama et al. (2013)
Borge	Peatland	QUB-565/G2: Borge unknown 15	2250	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-567/G1: Borge unknown 12	1500	–	–	Pilcher et al. (2005)
Borge	Peatland	QUB-567/G2: Borge unknown 13	1500	–	–	Pilcher et al. (2005)
Lapland dendro	Dendrochronology	–	1414	–	1414	Helama et al. (2013)
Lapland dendro	Dendrochronology	–	1408	–	1408	Helama et al. (2013)
Sellevollmyra	Peatland	SEL-3	1194	Mixed, 'AD 860'?	–	Vorren et al. (2007)
Indrepollen	Lake	N/A	N/A	AD 860, Tjornuvik B	1060	Pilcher et al. (2005)
Sellevollmyra	Peatland	SEL-2	804	Hekla-1	846	Vorren et al. (2007)
Sellevollmyra	Peatland	SEL-1	766	Hekla-1158?	792	Vorren et al. (2007)
Sellevollmyra	Peatland	SEL-0	680	Öræfajökull-1362?	588	Vorren et al. (2007)
Bødalsvatnet	Lake	Upper sample	N/A	Öræfajökull-1362?	588	Pilcher et al. (2005)

Credits: Balascio and Anderson (2016); Helama et al. (2013); Pilcher et al. (2005); Vorren et al. (2007).
Shard concentrations and geochemical composition are not reported here as they are not consistently reported in original reports. Please consult references.

particularly rich in high-resolution paleoenvironmental records, derived from a wide variety of proxy types.

Data were collected from the Arctic Holocene Proxy Climate Database (Sundqvist et al., 2014) and the NOAA (National Oceanographic Data Center) data repository, as well as by the courtesy of original authors (Sjögren et al., 2015). The selection of paleoenvironmental reconstructions was based on criteria of ecological relevance, data quality and resolution, as well as geographic distribution and coverage of proxy types. The geographic location of the paleoenvironmental records is given in Figure 4.

The mid- and late-Holocene tephrochronology of Arctic Norway

A further line of inquiry concerning the *Gressbakken* termination is the potential for long-range effects of distant eruptions. Such impacts have demonstrably led to pronounced climatic perturbations in the higher latitudes of Fennoscandia, with marked societal consequences on multiple occasions (Büntgen et al., 2016; Helama et al., 2013, 2018; Holopainen and Helama, 2009; Huhtamaa and Helama, 2017; Löwenborg, 2012; Sigl et al., 2015; Tvauri, 2014). Previously, a tephrochronological lattice has been assembled for the western coast of Northern Norway (Pilcher et al., 2005), although no attempts have ever been made at correlating these with the archeological record.

Attempts to investigate past human impacts of volcanically induced climate perturbation demand fairly high resolution of both the environmental and archeological/historical archives. With regard to Northern Fennoscandia, the existence of an annually resolved dendrochronology successfully correlated with volcanic Sulfur signatures in Greenland ice-cores (Helama et al., 2013) provides ideal conditions for such an investigation, especially as it can be matched with an extensive and well-curated archeological record. Numerous tephra occurrences are known from Northern Norway (Table 4). Several of the tephra layers have been geochemically related to known, mostly Icelandic, eruptions and some (e.g. the 6900 cal BP Lairg-A and 4200 cal BP Hekla-4 events) have been identified across multiple sites, and across Sweden (Watson et al., 2016). These tephras represent a robust fraction of Holocene volcanic activity in Iceland (cf. Lawson et al., 2012; Swindles et al., 2011; Watson et al., 2017).

The climatic, environmental, or societal impacts of the specific events depositing tephra in Northern Fennoscandia are not known. Considering the comparatively moderate magnitude (Volcanic Explosivity Index $\leqslant 5$) of most Icelandic eruptions (Larsen et al., 2001), the expected impact was most likely correspondingly moderate, if any. Yet, the socio-ecological effects of eruptive events, including effects at long range, are not always linearly correlated with eruptive magnitude (Riede, 2019; Sheets, 2012; Torrence, 2019; Zeidler, 2016). It is the indirect, climatic effects we would expect to mostly influence Northern Fennoscandia (e.g. Jenkins et al., 2015; Wilson et al., 2015). Especially in light of recent work considering the climatic forcing of Northern Hemisphere climate and its downstream effects on human societies in the Holocene, we here consider the dates of known eruptions in parallel with selected paleoenvironmental records and the *Gressbakken phase* evidence.

Results

Plotting the known eruptive impacts in Northern Norway (red crosses) against the stacked paleoenvironmental proxies and

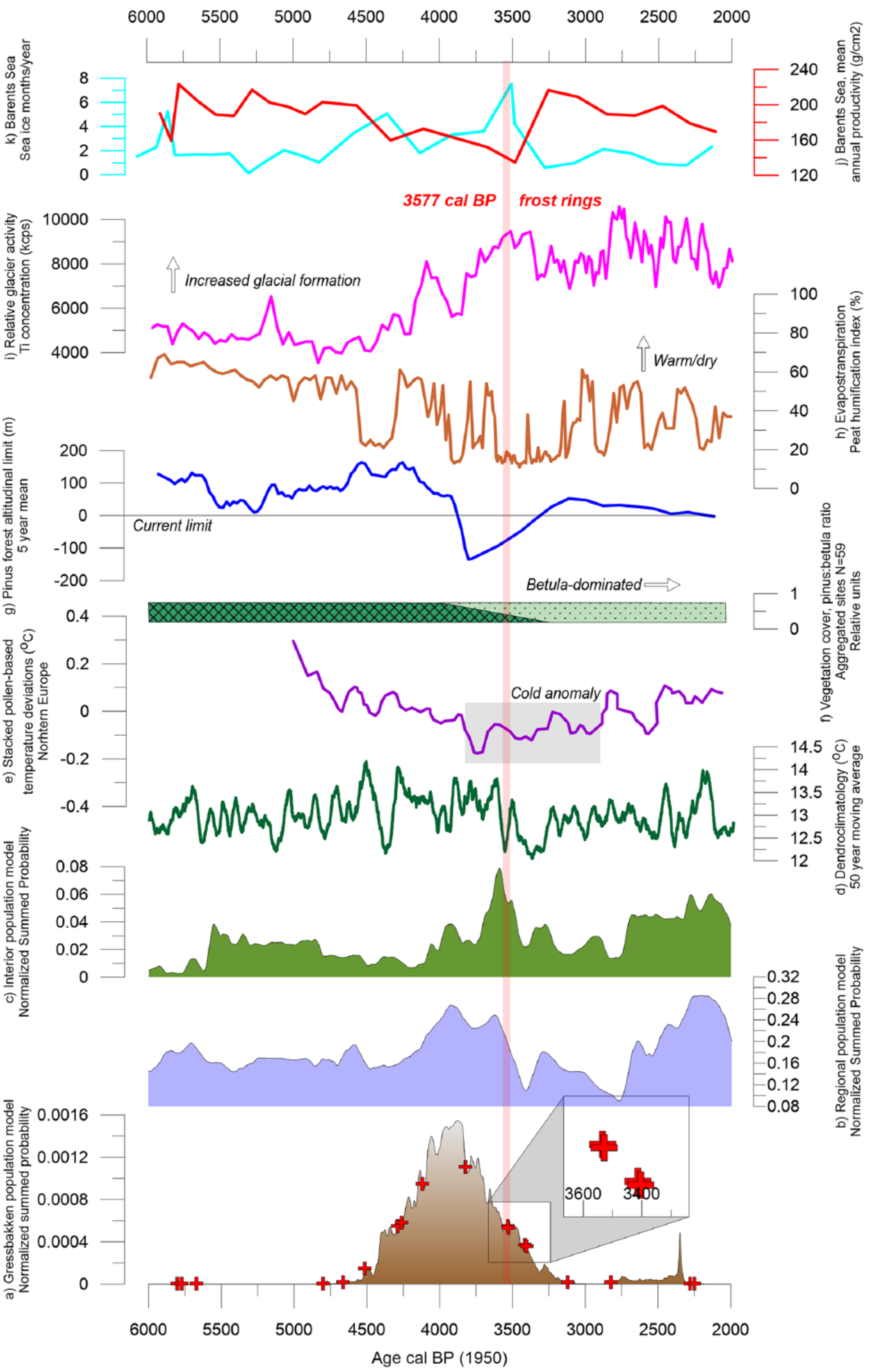

Figure 5. Stacked plots of population models and paleoenvironmental reconstructions. (a) Gressbakken population model, normalized summed probability. (b) Regional population model, normalized summed probability. (c) Interior population model, normalized summed probability. (d) Dendroclimatology (°C), 50-year moving average. (e) Stacked pollen-based temperature deviations (°C), Northern Europe. (f) Vegetation cover, pinus-betula ratio; aggregated sites $N = 59$; relative units. (g) Pinus forest altitudinal limit (m), 5-year mean.
(h) Evapotranspiration, peat humification index (%). (i) Relative glacier activity, Ti concentration (kcps). (j) Barents Sea, mean annual productivity (g/cm^2). (k) Barents Sea, sea ice months/year.
Red crosses at the bottom mark tephra occurrences as listed in Table 4 plotted against settlement intensity proxy of dated Gressbakken houses. Magnifier marks the eruptive cluster associated with the Thera eruptions with assumed direct implications for the human ecodynamics in the study area. Red vertical line marks the 3577 cal BP frost ring–producing event. See Table 3 for information on climate data. Plot (e) redrawn and adapted from Seppä et al. (2009: 531). Plot (f) redrawn and adapted from Damm et al. (2019: 5), data in Sjögren and Damm (2019).

palaeodemographic models shown in Figure 5 does not yield any consistent pattern. The Icelandic eruptions identified in Norway are of relatively minor magnitude, and it is not possible to ascribe any discernable effect to them. The Thera events are a different matter, as their ecological impact has been directly recorded in the local dendrochronology (Helama et al., 2013). Of particular interest is the cluster of four eruptive events that occurred within a 131-year time window at 3534, 3529, 3414, and 3403 cal BP, coinciding with the *Gressbakken* termination (Figure 5 – magnifier). At minimum, one of these is likely ascribable to the well-known yet contentiously dated Thera eruption (e.g. Friedrich et al., 2006; Pearson et al., 2018). One of very few frost rings identified throughout prehistoric Northern Europe has been identified and securely dated to 3577 cal BP in the local dendrochronology (Helama et al., 2019) – plotted as a vertical red bar in Figure 5. Such disrupted growth rings result from freezing temperatures during the growing season, in this case inferred for July and attributed to the effects of a dust veil following the Thera eruption. Furthermore, a number of eruptive events have been shown to occur within the mid-fourth millennium cal BP, suggesting that the *Gressbakken* termination occurred at a time of relatively frequent, large-scale eruptive events: North-American and Asian tephras have been identified in Northern Europe (Plunkett and Pilcher, 2018), several of which coincide closely with the *Gressbakken* termination, as well as Icelandic LBA-2 tephra has been identified in central Sweden, dated to 3550–3650 cal BP (Wastegård et al., 2009). Most notable among these is the massive eruption of Aniakchak (Alaska, USA) dated to 3590 cal BP, which itself had considerable effects on Arctic ecosystems and contemporaneous forager groups in Alaska (Riede et al., 2017; Tremayne and Winterhalder, 2017; VanderHoek and Nelson, 2007). Analogous to the 6th-century AD, these successive eruptive events appear to have had a marked and prolonged cooling effect in Northern Fennoscandia, clearly reflected in the Finnish Lapland dendrochronology (Helama et al., 2013).

The paleoenvironmental data show that prior to the mid-to-late-Holocene transition (4200 cal BP), climate conditions seem to have been uniformly quite stable and productive. This can be seen as the remnants of the Holocene Thermal Maximum providing reduced precipitation and higher temperatures (1 ± 0.5°C above modern conditions). The subsequent period (4000–3500 cal BP) was wetter and more unstable with temperatures closer to present-day conditions (±0.5°C), and a major reconfiguration of the local climate system transpired by the end of the period (Sjögren and Damm, 2019: 8). A major climate alteration took place between 3800–3000 cal BP, and was highly significant in terms of cementing the unstable, moist, and cooler conditions of the late-Holocene – identified in the stacked temperature deviations from across Northern Europe (Figure 5e; Seppä et al., 2009: 531). The transition marks the beginning of the neo-glaciation, witnessed locally by the reformation of the Lenangen glaciers (Lyngen, northern Troms) due to a major increase in winter precipitation (Bakke et al., 2005: 536). The included proxy on glacial dynamics (Figure 5i) demonstrates that the *Gressbakken phase* started alongside the re-advance of local glaciers (both in northern Troms and western Finnmark Counties) which had all but disappeared during the Holocene Thermal Maximum. The *Gressbakken* settlement intensity proxy continues to increase and reaches its apex during a marked glacial retreat. The regress of the Gressbakken settlement proxy from ~3700 cal BP corresponds to the most dramatic glacial increase throughout the mid-to-late-Holocene period, specifically between 3700 and 3400 cal BP.

This had major implications for vegetation cover in Northern Norway, as the tree-line retreated markedly into lower altitude and latitude. The incipient decline of the *Gressbakken* intensity proxy (Figure 5a) corresponds to a major drop in *Pinus* altitudinal limit of ~300 m and reduced latitudinal distribution with a shift toward *Betula* as the dominant forest species, demonstrated by Figure 5f and g. What is more, the reduced activity suggested by both the regional and interior models corresponds well with the prolonged cold anomaly 3800–3000 in Figure 5e. Pollen data (sites, $N = 59$) from the entire Finnmark region indicate a marked shift in the birch/pine ratio around 3600 cal BP in favor of birch, plotted in Figure 5f (Sjögren and Damm, 2019: 8). This is a vegetation response to wetter and/or colder climate, and corresponds directly to the peat humification index (Figure 5h). Significantly, the highest percentage of peat moss (Sphagnum) growth throughout the entire Holocene occurred 3600–3500 cal BP (Vorren et al., 2012: 23), which is a response to cold and moist conditions. This is also consistent with the dendrochronological data demonstrating an extreme cold spell centered on 3550 cal BP (Figure 5d; Grudd et al., 2002; Helama et al., 2013).

A general cooling trend throughout the *Gressbakken phase*, and particularly cold and adverse conditions around the termination are indicated by the marine proxies documenting plummeting productivity and peaking sea-ice concentrations closer to the eastern coast (Figure 5j and k).

When considering the first rigorous dating scheme for the *Gressbakken phase* (Figure 5a) and its climatic and cultural setting, we suggest 3500 cal BP as the end date for the *Gressbakken phase*. This is somewhat out of line with previous attempts at defining its temporal extent, and we therefore suggest that the Younger Stone Age/Early Metal Period transition might be pushed forward by about 300 years to 3500 cal BP and thereby aligning it more directly with the general Neolithic/Bronze Age transition in Northern Europe. The small increase in the *Gressbakken* activity proxy centered on 2500 cal BP is likely to be secondary reuse of *Gressbakken* houses by people pursuing a more mobile post-*Gressbakken* adaptation, a practice that is becoming ever more visible through increased dating efforts (Damm et al., 2019; Skandfer, 2012). The recognition that the classic *Gressbakken* houses might only have been one functional component of a larger settlement pattern including various other forms of habitations structures (Niemi and Oppvang, 2018: 79) does not undermine the dating results presented here. The activity intensity at other typologically separate habitation sites follows the same pattern, and thus corroborates the results of our dating scheme.

When compared to the regional population model (Figure 5b), it is clear that the *Gressbakken* occupation intensity proxy is the single most important contributor to the 4000 cal BP population peak. The implication is that the population dynamic of the *Gressbakken phase* is to a large extent the main driver of the total regional population fluctuations at the time. However, the regional population proxy keeps growing after the intersection with the collapsing *Gressbakken* proxy. This is explained by increased inland exploitation, with a marked peak at about 3600 cal BP (Figure 5c). Despite the low number of interior dates, the results are in strong accordance with the expectation of increased residential mobility and economic diversification as risk management responses during times of stress.

The result of reviewing the settlement data is an apparent hiatus in settlement activity following the *Gressbakken* termination (see Helskog, 1984: 47). Lower-elevation beach ridge sites in Varanger previously used to argue for post-*Gressbakken* continuous habitation, such as at the Veidneset and Angsnes peninsula (Hood, 2019b: 33) and at Mortensnes (Johansen and Odner, 1968; Schanche, 1988), show a hiatus of 2–4 m of vertical shoreline displacement following the *Gressbakken phase* before habitation structures reappear. The hiatus is further corroborated by investigations at the Nyelv site, in which major activity corresponds to the height of the *Gressbakken phase* (4000 cal BP), while documented activity ceases ~3650 cal BP along with a trend toward reduced indicators of settlement intensity (Niemi and Oppvang, 2018: 73). What is more, the recent investigation and dense dating of the houses at the Abelsborg site further substantiate this occupation hiatus, as all major activity seems to end along with the

Gressbakken phase (Oppvang, 2018). Critical factors such as the impact of later reuse and potential taphonomic biases in the preservation of lower elevation houses being more exposed to modern settlement should be kept in mind. Nonetheless, the pattern identified here seems to be consistent across multiple sites of different preservative states.

Outside Varanger, results from multiple and extensive excavations in western Finnmark contribute to the picture of large-scale changes, in line with the indices of the *Gressbakken* collapse. The multi-period sites of Slettnes, Melkøya, Skjærvika, and Fjellvika all testify to a drastic change in settlement type with the termination of the *Gressbakken phase*, involving a strong reduction of pit houses in favor of open-air sites. During the interval of the *Gressbakken phase*, large pit houses with marked entrances and the occasional preservation of rectangular stone-lined hearths occur in western Finnmark. Yet also here, they disappear during ~3600/3500 cal BP (e.g. Sundfjæra S11 (Hesjedal et al., 2009: 305), Slettnes F82 (Hesjedal et al., 1996: 124), and Skjærvika S27 (Henriksen and Valen, 2013: 276)). The processes characterizing the terminal *Gressbakken phase* in Finnmark appear to have had repercussions also for the inhabitants of present-day Troms, and possibly Nordland County as well. This is indicated by major shifts in economy and settlement patterns there (Arntzen, 2015; Blankholm, 2011).

As a consequence, recent accumulation of data underline rather than contradict the widespread impact of the *Gressbakken* termination – and go on to suggest a hiatus in occupation at multiple sites in the core area of the phenomenon. Significantly, the suggested termination of the *Gressbakken phase* (3500 cal BP) corresponds to one of the most pronounced cold periods in the entire Holocene, only surpassed by the 'Little Ice Age' and the 8.2-ka event, dated to 3800–3000 cal BP from a local multi-proxy reconstruction (Seppä et al., 2009: 531). This cold period marks a regime shift from the warmer, drier conditions of the Holocene Thermal Maximum to colder and wetter conditions in the late Holocene. The evidence therefore points in the direction of direct climate forcing of human demographic decline. This large-scale correlation is further explored below in terms of its possible middle-range causal mechanics.

Discussion

Hunter-gatherer societies have multiple risk management strategies at their disposal (Halstead and O'Shea, 1989; Minc and Smith, 1989). Most commonly, a combination of strategies would be applied in most crisis situations, although technological limits would act on, for example, the ability to store food, while ecological constraints limit the degrees to which resource-use can be intensified or additional resources be added to the repertoire. In the transition from *Gressbakken* to post-*Gressbakken*, we find a set of response mechanisms in accordance with the predictions stated initially, such as the break-up of semi-sedentary coastal settlements, as well as a significantly more dispersed occurrence of sites and the end of midden accumulation all testifying to increased mobility (Table 5).

Based on the environmental setting of the initial *Gressbakken phase*, the development of the substantial houses during this time may tentatively be explained as an adaptation to a climatic shift during a time of particulate cold and moist climate, resulting in increased winter storminess and heavy snowfall (Björckl and Clemmensen, 2004; Vorren et al., 2007: 272). Populations in Finnmark may have responded by aggregating in larger numbers during winter and by constructing sturdier dwellings. This is inferred from house morphology and is to some extent backed by faunal seasonal reconstructions indicating potential year-around use, with a focus on particular dense winter-spring habitation related to cod exploitation, which spawns on these coasts during winter (Olsen, 1967; Renouf, 1989, cf. Hodgetts, 2010).

Numerous paleoenvironmental records of Northern Norway strongly indicate, however, a downward spiral following the climate shift at 3800 cal BP as the onset of significantly colder temperatures and hence less productive environs, with drastic climate events centered on the period around 3600 cal BP. In fact, one of the Holocene's lowest annual temperatures has been inferred for 3534 cal BP as the impact of the Santorini eruption, as part of a progressive cooling toward this chilly nadir (Helama et al., 2013: 4). The wetter and cooler conditions (the increased *effective precipitation*) following the 3800 cal BP climate shift raised the water table and resulted in widespread paludification (Sjögren and Damm, 2019: 12; Vorren et al., 2007: 272). Such conditions are highly reductive to pine growth, succession, and reproduction. The transition from mixed pine forest to a sparser vegetation dominated by birch is a general trend during late-Holocene Northern Fennoscandian, and a distinct reduction in *Pinus* has been demonstrated for the core *Gressbakken* area in eastern Finnmark (Hicks and Hyvärinen, 1997; Karlsson et al., 2007; Sjögren and Damm, 2019). If the advent of the *Gressbakken phase* was (partially) a response to the snowy winters by building large, sturdy, and wood-demanding structures, the rapidly retreating tree-line potentially made it more difficult to keep up the construction and maintenance of such resource-demanding houses. If so, it would be a predictable outcome if such house technology was abandoned in favor of less wood-demanding construction types. Despite the fact that Siberian drift wood was likely present regardless of vegetation cover in Varanger, rapid forest decline increased house maintenance costs through foraging and preparation time expenditures, as well as restraints on wood technology and fuel.

The climate shift and forest decline also had major impacts on biogeography. It has been suggested that the historic and current migratory behavior of large reindeer populations only formed along with the late-Holocene deforestation and that a sedentary (forest) ecotype variant of reindeer populated the coastal region of Northern Norway during the forest maximum (8300–4500 cal BP; Hood, 2019a: 23). As such, the *Gressbakken* termination would have been particularly driven by so-called 'rain-on-snow' events, forming a solid ice crust impenetrable to reindeer. Mass starvation can occur (Burch, 2012; Chernow, 1985; Spiess, 1979) and is known both historically and from contemporary accounts as a cause of reindeer population collapse (Forbes et al., 2016; Turunen et al., 2016; Tyler, 2010). In addition, deep snow increases predation by wolves and wolverines (Mattisson et al., 2016), and extended cold combined with deep snow is known to spike mortality among Cervidae, especially elk (*Alces alces*) (Kojola et al., 2006). Reindeer would therefore become less accessible on the coast throughout the *Gressbakken phase*. Note that to the maritime-adapted *Gressbakken* population, the reduced availability of reindeer most likely was less problematic in terms of reduced caloric return rates but rather created bottlenecks in non-food ungulate products. As suggested by ethnographic insights, reindeer products are critical for marine hunter-gatherers (Smith, 1991; Stenton, 1991b). The non-negotiable need for reindeer hides in particular has been stressed repeatedly, as they provide the only product meeting the thermal requirements of Arctic winter clothing in the study area. Arguably, reindeer played so important a role in the more quasi-sedentary, maritime adaptive strategy of the *Gressbakken phase* that the observable material culture change in favor of increased mobility and inland exploitation could be a response to reduced reindeer numbers or increased dispersion, either of which would have made the procurement of suitable hides more difficult and costly.

The archaeofaunal evidence from the *Gressbakken phase* supports the importance of reindeer products: Despite low absolute abundance, reindeer bones were a fundamental part of the technical requirement for the maritime adaptation, not just in terms of

Table 5. Evidence for the application of key risk management strategies in the termination of the Gressbakken phase.

General coping strategies	Continuum of stress conditions		Gressbakken response evidence
	Low severity (localized/short-term)	High severity (regional/long-term)	
Diversification	Local secondary resources	Extra-regional resources	Shift in adaptive strategy
Mobility	Increased intra-regional logistic/ residential mobility	Inter-regional migration	Settlement hiatus, increased residential mobility, possible migration, end of midden accumulation
Storage	Intra-community (physical)	Inter-community (social storage)	Regional population decline
Exchange	Generalized reciprocity and informal sharing at intra-societal level	Delayed reciprocity and formalized trade at inter-regional level or negative reciprocity (raiding, theft)	Lack of trade networks and complementary adapted groups. Disintegration of inter-regional Gressbakken complex

hides and sinews, but also as raw material for the production of fish hooks and harpoons (Hodgetts, 2000). The distribution of reindeer body elements indicates that reindeer were neither hunted nor slaughtered at the settlement sites. However, low meat/fat utility body elements were selected primarily on the basis of tool-making suitability and brought to habitation sites, and the very low proportion of split bones for marrow extraction at *Gressbakken* sites further highlights the non-dietary function of reindeer – used to argue that the population was under no dietary stress (Hodgetts, 2000). Regardless, any major restructuration of reindeer migration routes or demographic bottlenecks would have important implications for the human population at hand.

Concerning the impact of volcanism and related to the identified tephra-occurrences in Northern Norway, even light tephra fall could have aggravated the crisis initiated by the deteriorating climate. It has been demonstrated that tephra-laden vegetation can lead to severe dental abrasion in animals and humans, with the impact being particularly strong on grazing animals (Riede and Wheeler, 2009). In addition, very fine-grained volcanic ash can enter the airways and cause respiratory irritation alongside potential longer term effects due to the chemical loading of the particles (Horwell and Baxter, 2006; Horwell et al., 2015). A particularly interesting effect in the case of Northern Norway is the detrimental impact of the acidic ash fallout and acid rain on lichen and mosses which form the dietary basis of reindeer. This has been demonstrated to have had severe impact on comparable prehistoric hunter-gatherers in Alaska (Riede et al., 2017; VanderHoek and Nelson, 2007), where it led to the Alaska-wide population decline and disappearance of the Arctic Small Tool tradition following the 3600 cal BP Aniakchak eruption and an hypothesized caribou collapse (Tremayne and Brown, 2017). Note that direct, local ashfall is not a requirement for this to have an effect.

With a drop in net primary productivity (NPP) following reduced effective temperature (ET) and an increase in resource patchiness along with a potential destabilization of the existing bio-geographical regime, mobility needs to be adjusted toward the forager-end of the adaptive spectrum in order to minimize risk and uphold caloric return rates (Solich and Bradtmöller, 2017; Whallon, 2006). Increasing resource patchiness is expected to occur from 3800 cal BP as an initial consequence of deforestation. Given the existence and availability of highly productive and stable patches, the ideal free distribution predicts *reduced* residential mobility under such conditions of increasing patchiness (Bettinger and Grote, 2016). One might have expected an economic shift toward intensification of marine resources as a response mechanism to maintain return rates – which arguably was the case in Kodiak, Alaska, under similar conditions (Fitzhugh, 2003). However, this is contrary to what we find, as residential mobility seems to *increase* along with heightened resource patchiness of the terrestrial environment and increased interior exploitation (Figure 5a). This result is more in line with the economic response by Thule Inuit to reduced caribou densities on Baffin Island, Canada, suggesting an inland-oriented procurement strategy during periods of caribou population decline (Stenton, 1991a).

Despite the uncertainty of how the observed Late-Holocene cooling affected aquatic resources, the available marine productivity measures (Figure 5i) suggest an absolute low corresponding to the *Gressbakken* termination and the eruptions around this time. We therefore attribute the societal impacts as documented archeologically to a cross-ecotone productivity decline along with a lack of any densely packed and highly abundant marine resource able to compensate the reduction in terrestrial productivity, as well as the inherent need for non-caloric ungulate products. In all, this environmental setting would drive down the sustainable patch-specific foraging time, and result in both more frequent moves and shorter durations of stay – which is nicely mirrored in the occupation hiatus and settlement restructuration following the *Gressbakken phase*. Increased mobility has implications for life-history decisions, for birth-spacing and fertility, and hence for population density (MacDonald and Hewlett, 1999; Surovell, 2000). Downstream, lower temperatures are strongly correlated with reduced population densities (Binford, 2001; Tallavaara et al., 2015) – although not necessarily in terms of packing in Arctic environments (for a convincing case of 'climate deteriorations' as a positive trend in the Arctic, see Desjardins (2013)).

Recent aDNA studies have demonstrated the influx and admixture of Siberian genetic material into the gene pool of adjacent areas in Finland and particularly Murmansk Oblast in Russia by 3500 cal BP (Lamnidis et al., 2018; Sarkissian et al., 2013). The sampled individuals from Bolshoy Oleni Ostrov were uncovered in graves containing multiple finds of asbestos-tempered textile/imitated textile ceramics and Lovozero ware (Murashkin et al., 2016). This ceramic type has a distinct eastern distribution and new, direct dating efforts suggest that it was introduced to Northern Norway at the time of the *Gressbakken* termination (Hop, 2016; Lavento, 2001; Oppvang, 2009; Pääkkönen et al., 2018; Seitsonen et al., 2012). The influx of eastern genetic and archeological material corresponding to the major demographic and economic shift in Northern Norway is intriguing and potentially indicative of more extensive population movements, albeit beyond our ability to demonstrate empirically at this point. Given an absolute population decline, along with a shift in economy and settlement pattern, the *Gressbakken* collapse may have further facilitated a successful in-migration from the southeast – thus corresponding to ecological source/sink dynamics (Lamb et al., 2017; Robertson and Hutto, 2006).

As a final complication to the *Gressbakken* system, there is currently no reliable evidence of networks that might help mitigate rapid and high-impact climate change. This suggests that the reliance on complementary adaptations in which social networks are maintained to be activated during times of environmental stress as documented, for instance, in the Canadian Arctic by Minc and Smith (1989), would be difficult to implement

(Tremayne and Winterhalder, 2017). A scenario in which coastal populations in Northern Norway interact with interior groups presupposes the existence of separate populations with specialized economies for such a risk reduction mechanism to have any effect. Although repeatedly promoted (e.g. Olsen, 1994: 76, 84), such claims are empirically unsubstantiated and have not become any less so with the accumulation of recent, large-scale interior surveys (Skandfer et al., 2019). The seeming lack of such safety nets among a near-sedentary coastal population is hypothesized to have reduced resilience and required other risk-reduction responses during times of crises. The indication of increased residential mobility is therefore highly consistent with expectations derived from foraging models (Bettinger and Grote, 2016; Halstead and O'Shea, 1989; Kelly, 1983; Lupo, 2007; Metcalfe and Barlow, 1992; Venkataraman et al., 2017).

Concerning networks as a fallback strategy, a predictable outcome of increasing population numbers and packing, such as witnessed at *Gressbakken* coastal sites (cf. Figure 5a), is a more self-sustained mating network with less incentive to introduce external genetic input. If so, population growth during, but potentially also some time prior to the *Gressbakken phase*, might have been an important driver of regionalism. We propose that regionalism of the *Gressbakken phase* made the population more susceptible to environmental change, as reduced network fluidity following increased sedentism weakens the important safety-valve that networks demonstrably provide to hunter-gatherer populations globally (Binford, 2001; Kelly, 2013). Reliable proxies for negative reciprocity (Table 4) such as territoriality, inequality, and conflict is remarkably absent throughout the archeological record of Stone Age Northern Norway – also when compared to the apparent evidence from adjacent Northern Finland and to some extent Sweden—such as large defensive structures (Tallavaara and Pesonen, 2018), trends of increased territoriality/regionalism, large pit house construction and technological dissemination (Forsberg, 2012; Holmblad, 2010; Mökkönen, 2011: 57), and even alleged social stratification (Vaneeckhout, 2010: 12). Either way, exclusive home ranges are a common outcome of increased locational investments (Binford, 1990; Borrero and Barberena, 2006; Cashdan et al., 1983; Smith and McNees, 1999). This minimal form of territoriality might therefore be a reasonable expectation of the *Gressbakken phase* as well, given population packing and near-sedentism. As it is, we propose that the increased sedentism and regionalism of the *Gressbakken phase*, combined with failing adaptive responses, resulted in reduced resilience in the face of rapid environmental change (Sheets, 1999, 2001, 2012). The results testify to a convergent catastrophe scenario, with the ~3550 cal BP eruptions providing the final stressor in a series of hardships that finally exceeded the adaptive mitigation capabilities/responses of the North Norwegian population. As such, these findings may suggest that the *Gressbakken* collapse is the northernmost demonstration of social and demographic upheavals contemporaneous with the European Bronze Age disturbance, as mapped by Risch and Meller (2015).

Conclusion

Based on a review of paleoenvironmental, tephrochronological, archeological data and palaeodemographic modeling, we argue that the termination of the North Norwegian *Gressbakken phase* of collector-like hunter-gatherers corresponds to – and was likely caused by – major changes in the biophysical environment. We show that the *Gressbakken phase* came to an end as a result of the cumulative effect of multiple stressors restricting the response options of this population (Dyer, 2002: 164; Riede et al., 2017). We believe this created a scenario of decline in line with what has been termed 'convergent catastrophes' (Moseley, 2002: 203).

We propose a chain of causal factors where a terrestrial ecosystem restructuring following the 3800 cal BP climate shift affected human communities through reduced terrestrial biomass and sparser wood coverage, resulting in lowered ungulate densities. These trends were further aggravated by multiple volcanic events around 3550 cal BP, leading to substantive temperature declines at annual-to-decadal scales in local paleoenvironmental proxies and mapped through a compilation of tephra occurrences, also evidenced by the 3577 cal BP dendrochronological frost rings. These changes drove increased logistic/residential mobility in order to acquire the necessary reindeer products, which in turn necessitate demographic and technological adjustments. As predicted by human ecodynamic research, population numbers are highly dependent on temperature and primary productivity (Tallavaara et al., 2018), and the ethnographic record shows a negative impact of residential mobility on reproductive fitness (Hamilton et al., 2016; Kelly, 2013; Page et al., 2016). It is therefore likely that the *Gressbakken* population downturn evidenced across the regional and environ-specific palaeodemographic models presented here, actually entailed some element of absolute population decline. Significantly, the review of risk-mitigation strategies available to the *Gressbakken* population suggests some real adaptive limitations. The near-sedentism and higher locational investments seem to have resulted in reduced resilience in the face of rapid biophysical changes. Combined with the lack of complementary adapted inland populations for network mitigation of environmental risks, we suggest that the termination of the *Gressbakken phase* was an adaptive response to multi-layered ecodynamic forcing.

Acknowledgements

EKJ would like to express a sincere gratitude to professor Charlotte Damm (UiT) for helpful responses and proof-reading, and professor Bryan Hood (UiT) for introducing him to the topics at hand and for the selfless sharing of data, ideas, and time. The authors would also like to thank to the two anonymous reviewers of this paper who provided highly constructive and helpful feedback greatly improving our paper.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This work was supported by the 'Stone Age Demographics' project funded by the Research Council of Norway (Grant No. 261760) and through a doctoral fellowship funded by UiT–The Arctic University of Norway. Additional financial support was provided by the Aarhus University Research Foundation (AUFF) in the form of a visiting PhD student grant. This allowed an extended stay at Aarhus University, facilitating the cooperation needed to produce the current research.

ORCID iD

Erlend Kirkeng Jørgensen https://orcid.org/0000-0002-8573-4489

Supplementary material

All data presented in this paper is attached as an appendix (Excel spreadsheet).

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