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Maritime Human Ecodynamics of Stone Age Arctic Norway

Developing middle-range causal linkages between climate forcing, demography, and technological responses

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Cover photo: “Uveir langs kysten” (English: “Storm on the coast”). Hand-colored dias. 1900-1940.
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Preface and acknowledgment

"What are the major issues currently pushing the boundaries of archaeology? And what are the major problems archaeology needs to solve in order to advance as a science?" - he asked causally, not knowing how unsettling these questions were. My friend posed these questions in the inescapable setting of being crammed into a fully packed car, going to a mountain cabin for a new year's celebration some years back. Of military background and no prior experience with archaeology, he had no idea how troublesome these questions were. I cannot recall what I told him in response. The answer was probably not very informative or interesting to him, and frankly, to this day, I am not able to give a straight answer to these questions.

I have come across versions of this question at various points in my academic career, and it has always struck a chord with me. Being able to pinpoint the crucial questions epitomizes what constitutes great thinking in general, and great science specifically. In the case of archaeology however, making progress can often be frustratingly difficult. This is a natural consequence of being "the science of incomplete and insufficient data". The many fundamental problems in reconstructing past systems from contemporary fragments likely make us susceptible to myopic research: getting hung up on improving the precision of tools, methods and concepts. As an empirical science, striving for such improvements are both necessary and justifiable. Yet it should not stop us from posing grand questions. This is because no detailed study of even the most particular of things makes much sense without reference to an overarching problem. The very validation and reason for performing in-depth, particularistic research, is by contributing solid, empirical evidence (however, small) to the bigger picture. This is afforded through feedbacks between the large and the small.

There were some fear already in the 1970´s that the drive towards ever more minute details and methodological precision was gained at the cost of integrative oversight (Gjessing 1977:13). This, it was believed, finally would result in a dismal state where "archaeologists act like deaf men answering questions no one asked" and that "archeology suffers from cataracts and requires surgery to regain perspective" (Gjessing 1977:13)[my translation]. Contrary to such bleak predictions, increasing scientific influences on archaeology have rekindled interest in classic culture-historical topics and fueled more integrative, interdisciplinary research into the human past – not only as a cultural, but equally as socioecological processes.

Through my work, I have attempted to tackle the uncomfortable stretch of combining both the very small with the very big. I have taken on the task of poking my nose into the grand challenges of archaeology, while simultaneously striving to maintain a solid empirical footing. I cannot determine the degree of my success, but I hope I can be commended for my efforts. The ambition is to contribute a useful building block to the scientific community.

The realization of this thesis is communal to its core – although its production has primarily been confined to the privacy of my office. For one, I am truly grateful for the institutional arrangement and political willingness in Norway to spend people's hard-earned tax money on seemingly irrelevant and marginal research projects such as what I present here. I have no illusions as to the insignificance of this work in the grander scheme of things, yet my utter enjoyment in working with this has only been possible through working people not rebelling against the public spending on basic research – and for that I am grateful. This has provided me with the opportunity to come to Tromsø and realize an academic dream. Globally and historically, this is a great privilege that I fully appreciate.

This work is also communal in the sense that the majority of data, methods, analytical categories etc. emanate from the work of previous scholars and practitioners. There are so many contributors on which this work is contingent and dependent that I cannot name them all. For the sake of brevity, I only mention the most significant supporters of this work.

I thank Charlotte Damm (project leader and internal supervisor), for letting me participate in an interesting and stimulating project, for providing robust and predictable guidelines and expectations, and making sure my project stayed on track. You provided the culture-historical anchor within an otherwise lofty project and helped stifle my eclectic impulse to pursue my very wide spectrum of interests all at once, while providing the trust and freedom to develop my research.

I thank Felix Riede (external supervisor), for the opportunity to visit Århus on multiple occasions. I am grateful for the now long history of our relationship, following the serendipity of meeting at the Norwegian Archaeological Conference in Tromsø 2013. The discovery of our mutual research interests and the kind act of taking me in and supporting my work already at the MA level, has been highly formative for my academic career.

I am deeply indebted to Bryan Hood (internal supervisor) for the truly selfless sharing of time and knowledge, for language corrections, and for acting as my partner in (ecodeterministic) crime. I have probably worn down the doorstep to your office with my many visits. Thank you for your patience and dedication, as well as our informal tradition of Friday evening discussion sessions.

Miikka Tallavaara has also been a major supporter, to the extent that this thesis would not have been possible without his very generous sharing of technical expertise. I have benefitted greatly from the introduction to palaeodemographic modelling and for acting as technical support periodically. Your relentless dedication to precision is admirable, and has been a very healthy correction to my natural tendency to bluntness.

Dedication comes at a cost. Nowhere is this clearer than in the case of my parents who have selflessly exempted me from familial requirements in a time that has been particularly hard and would have benefitted from me taking my share of care work. Thank you for the freedom and support.

During my time working this project I have been diagnosed with a chronic rheumatic disease. Living with constant pain and discomfort is not the physical attribute most compatible with that of doing intellectual work requiring focus and dedication. In fact, it had simply not been bearable without my wife Terese´s support. Were it not for your generosity and consideration in giving up settled life in the lushness and comfort of our home area to the complete unknown of the Artic, this work had never happened. When I applied for this position, none of us thought I would get it, and so we were confronted with the problem of deciding what to do upon getting the offer of doing a PhD in Tromsø. Deciding to go was no small thing, and although it has been challenging at times, it has more than anything been an adventure of the exciting kind. Thank you for everything.

Hessfjord, Ringvassøy 6.4.2020

(in societal and physical isolation due to the COVID-19 pandemic and avalanches blocking the road)

Summary

This thesis has two overarching goals. One is to reconstruct human population dynamics in Stone Age Arctic Norway (12.000-2000 cal BP). The other is to explain the demographic changes as population ecological phenomena. Thus conceived, the project is fundamentally engaged in contributing to the Human Ecodynamic research agenda of investigating the co-evolution of human and natural systems. This agenda is operationalized as a set of objectives:

- Reconstruct relative population size changes through time.
- Compare with relevant palaeoenvironmental records.
- Provide detailed case studies of human adaptive responses to ecological change.
- Establish middle-range causal mechanisms connecting macro-scale climate forcing with micro-scale human risk reduction strategies, by way of aggregated demographic, technological and ecological effects.
- Track the evolution of maritime adaptation in the region.

The justification for the project is provided by the general lack of integrated socioecological research of Arctic Norwegian prehistory. As such, this project attempts to plug a marked knowledge gap concerning the causal role of environmental drivers in long-term cultural change. Equally important however, is the ambition of contributing to the general understanding of human ecology and adaptability by way of generalizable, empirical results, and case studies of causal mechanisms driving integrated socioecological change. An important premise of this work is that such is achievable only through the study the ecological and environmental drivers of change in human cultural systems.

The project has a marked interdisciplinary profile, relying on data and analytical tools provided by various palaeo-disciplines. It synthesizes large sets of proxy data concerning human demographic variation, environmental dynamics and technological mitigation capabilities – trying to get at the adaptive features of a high-latitude, maritime adapted foraging population. Past human demographic changes are modelled on the basis of the summed probability distribution method, applied to the North Norwegian Radiocarbon Record dataset newly compiled for this very purpose.

The outputs consist of four peer-reviewed papers and an extensive introductory text presenting important background information and analytical considerations. Result highlights are: 1) The demonstration of repeated and significant population cycles throughout the 10.000-year study period. 2) That both long-term population trends and shorter-term demographic events are shown to be strongly regulated by environmental drivers. 3) Detailed case-studies demonstrate how adaptive and technological changes are interrelated with the environmental and demographic changes. The various papers explore and attempt to explain the particular processes that produce correlated demographic and environmental dynamics. Consequently, a major result of this project is developing a middle-range causal framework for tracing the impact of large-scale environmental drivers on human adaptive responses, as mediated through resource availability, risk reduction strategies and shifts in subsistence technologies.

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1 Introduction

What do we know about the demography of prehistoric populations in the northern parts of Norway and how they adapted to the climatic changes of the Holocene? Prior to the last couple of years: very little. This thesis attempts to remedy some of the associated blank spots, and does so in tandem with the collaborators within the overall research project "*Stone Age Demographics: multi-scale exploration of population variations and dynamics"* (*Stone Age Demographics*) based at UiT – The Arctic University of Norway.

At first glance, the lack of knowledge concerning human palaeodemography and responses to environmental changes may not induce much excitement or realize any apparent need, archaeologically or contemporary. However, the study of demography (the composition and change within a population through time) is essential in getting at past states of affairs. This is true for nearly every domain of human life, societal development and the evolution of species. Because while most other variables display shifting distributions within and between the human populations that have ever populated the earth, demography is omnipresent. This alone provides a powerful justification for studying demography in any human system, be it contemporary or in the past. What is more, the fundamental role of demography in shaping human societies is key to archaeology, as the study of populations provides an obvious and direct link to other societies across space and time. Esther Boserup (1993[1965]) famously coined population density as an independent variable in human economic systems (cause rather than consequence), thus turning Thomas Malthus´ (1798) classical demography on its head. However, the causal efficacy of demography in relation to the other system components of human societies is neither linear nor mono-causal. This is because demography is equally explanans and explanandum – that is, the *result* as much as the *driver* of change in other variables, discussed in [Section 4.6.1.Equifinality]. Yet, in constituting one of the fundamental parameters of human social life, demography is among the few variables that can be directly translated into formalized generalization and compared between otherwise disparate. We cannot get very far in explaining change in the past without considering demography, it seems.

The above points are fruitfully illustrated in the artistic reconstruction of a Late Stone Age coastal settlement at Melkøya Island, Finnmark County (Fig.1). How we envision past people is strongly dependent upon demographic assumptions concerning child mortality, the ratio of offspring to parents, age distribution and sex ratio, be it conscious or not. This includes important characteristics such as community structure (ranked or egalitarian), settlement pattern (sedentary or mobile), population density (packed or distributed), site size, economic adaptation (depending on group cooperation or not), technological complexity (dependent on functional division of labor and specialization or not), social learning and knowledge transmission, territoriality (or not, necessary/possible to defend areas), mating networks, trade, migration, ideology etc. Although this thesis never moves into this level of demographic detail, it is important to recognize the underlying role of demography as a decisive variable from the beginning. The basic premise applied here is that there is no randomness to the way population size and -structure fundamentally affects most other variables concerning human ecology, culture, and social life. Demography matters.

Figure 1 Illustration of a Late Stone Age coastal habitation site. Endre Skandfer © UiT The Arctic University Museum of Norway

Despite its fundamental importance, demography does not emerge or evolve in a vacuum. As such, this work attempts to piece together the interrelated dynamics of human populations and their natural environment. This interrelation produces "*socioecological"* systems in which both external environmental and internal cultural condition conjoin to interact with the critical variable of demography. Taking human demography to be the link between the factors external and internal to culture and adaptation, is a leading premise of the human ecodynamic approach taken here [Section 1.2.]. Thus, a central tenet to this work is regarding human populations and adaptive responses from an ecological perspective. Applying population ecological models and explanatory concepts help bring structure to the apparent historical particularism and contingency of human material culture. After all, the mechanisms driving population change and adaptation in humans are essentially "*ecological*" mechanisms, and no different from other species.

The scope of this thesis is primarily that of Arctic Norway (delimited to Northern Troms and Finnmark Counties) within the timeframe of the Holocene period. The focus is exclusively directed at the dynamics of foraging populations in the area and thus the timeframe is restricted to the first ca 9500 years following post-glacial colonization, and until food-producing economies and metallurgy make any lasting impact (11.500 – 2000 cal BP), with particular emphasis on the interval 7000-3000 cal BP. Given the particular ecological, geographical and climatic properties of the study area, that may best be conceived of as a coastal biome, combined with the ensuing adaptive strategies of the Stone Age population, this thesis has a strong "*maritime*" focus. Maritime hunter-gatherers are known to display a set of particular demographic and adaptive properties, often diverging markedly from the general ethnography of iconic (terrestrial) hunter-gatherers (Bailey and Milner 2002; Binford 1990, 2001; Erlandson 2001; Fitzhugh 2016; Kelly 2013; Renouf 1984; Yesner 1980). Such particular qualities often include greatly elevated population numbers and densities, sedentism, high locational investment, mass hunting and bulk processing of packed resources for lean-season consumption, high levels of techno-complexity, often followed by social stratification, defended territories and extensive trading networks. The basis for developing such characteristics fundamentally rely on occupying highly productive, coastal biomes. Although the Arctic Norwegian coast boasts what is an exceptionally productive coastline in the circumpolar region, the evolution of high-latitude maritime adaptive strategies has never been systematically investigated in the area, let alone the ecological basis for these characteristics in the archaeological past. Instead, the reliance on coastal resources has been treated intuitively as a stable economy, and arguably, taken for granted. The maritime adaptive strategy of the Arctic Norwegian coastal biome has therefore remained undertheorized. However, adaptive pressures are constantly active and respond to any rearrangement of the fitness landscape. Given the 9500-year approximate timeframe of this study, as well as the known environmental and ecological dynamics occurring within this timeframe, the human adaptive responses highly likely varied as well and should merit dedicated study.

Globally, demography has been recognized as a decisive factor in explaining cultural change. Locally however, a standstill was reached between two camps in the 1980/90s debate over demography and settlement patterns in Stone Age Artic Norway: some proposing village-like conditions of multiple contemporaneous houses, year-round sedentism, significant population densities and territories (e.g. Renouf 1989; Schanche 1995). Others proposed few and small contemporaneous households integrated into a more dynamic mobility pattern (e.g. Engelstad 1984; Helskog 1984). This debate was rather spatiotemporally specific to the Gressbakken phase (4200-3500 cal BP) mainly of the Varangerfjord area in eastern Finnmark and did not generate a general interest in demography as a research topic in itself. Regardless, given the data and analytical tools at the time, transcending this divide and bringing robust empirical evidence to the table proved difficult. Henceforth, palaeodemography lost traction as a research topic in Arctic Norwegian archaeology, also in concert with an international shift in research interests toward other issues. An important inducement to this work is to demonstrate that the standstill of earlier demographic deliberations in the study area can be overcome by analyzing and integrating the archaeological record in combination with its wider ecological setting.

As such, the prospects for reconstructing multi-proxy timeseries of past human and natural systems, as well as identifying and explaining change in integrated socioecological systems are radically improved (cf. Kristiansen 2014). This has reinvigorated palaeodemography and human ecodynamic research. These particular interests have been fortunate in profiting from technical advances in the sciences, to the point that human ecodynamic research recently has become central to the global archaeological community. Recent advances of scientific methods and computational power provide archaeology with fantastically detailed information. Being able to extract the genome of extinct individuals, reconstructing health, diet, and mobility etc. is truly astounding, and is an important step for archaeology towards making substantial contributions to wider ecological and evolutionary research agendas (e.g. life history theory). Yet, viewed under the scientific outlook applied here, the value of such detailed information is only proportional to the extent that it provides building blocks for generalizable knowledge – that is, being aggregated into larger units of empirical trends and explanatory principles. Thus, a central tenet of this thesis is stressing the importance of establishing middle-range causal mechanisms for connecting the micro and macro scale of archaeological analysis in order to get at causal theory building.

In sum, this project builds on and combines recent technical advances and analytical trends in pursuing long-term human adaptive changes within an ecological framework. Not only is this applied to a new region, but it also provides innovation in the explicit attempt at developing middle-range causal linkages between the decisive variables of demography, environmental conditions and adaptive strategies. This way, the project contributes to global archaeology and Human Ecodynamic research in identifying mechanisms responsible for transforming micro-scaled constituents into macro-scaled consequences.

1.1 Papers

The following publications make up this dissertation and are referred to accordingly during this introductory text:

Paper 1: Jørgensen, E. K. 2018. The palaeodemographic and environmental dynamics of prehistoric Arctic Norway: An overview of human-climate covariation. (published, Quaternary International).

Paper 2: Jørgensen, E. K., and Riede, F. 2019. 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. (published, The Holocene)

Paper 3: Jørgensen, E. K., Pesonen, P., and Tallavaara, M. 2020. Climatic changes cause synchronous population dynamics and adaptive strategies among coastal hunter-gatherers in Holocene northern Europe (published, Quaternary Research)

Paper 4: Jørgensen, E. K. 2020. Scalar effects in ground slate technology and the adaptive consequences for circumpolar maritime hunter-gatherers. (published, Journal of Archaeological Method and Theory)

The papers in their entirety can be found at the end of this document.

1.2 Study area and temporal interval

The selected geographical area and time interval under scrutiny in this thesis is defined as a set of nested spatiotemporal units [cf. Section 3.3. Scalability as structure]. The primary study area is to a large extent defined by the focus of the *Stone Age Demographics* research project (NFR project number 261760) on Arctic Norway, particularly western Finnmark County (Damm et al. 2019:2–4).[1] The ambition of the overall project group was to employ the substantial legacy data deriving from former research projects and in particular from recent extensive development led investigations. The sheer quantity of data in this region make this area highly suitable for aggregate data analysis and synthesis. The division of labor within the project group has been scaled, with the individual contributions corresponding to specific analytical scales and scopes of research. These are ultimately interlinked through synthetic integration.

As part of the *Stone Age Demographics* group, my project was specifically designed as a study of supra-regional trends, responding to the project call for "considerations of spatial and temporal demographic fluctuations at a regional and interregional level, including comparisons between regions".[2] The primary geographical frame is that of the coast of northern Troms and Finnmark counties while also drawing on relevant comparisons with adjacent areas across northern Fennoscandia, and occasionally, throughout the Circumpolar region. The northern sector of Arctic Norway is by far the best documented through surveys and excavations, as exceedingly few projects have targeted the southern sector (Nordland and southern Troms Counties), with existing studies of the southern sector being limited with regard to geography and chronology (e.g. Bjerck's study of Mesolithic trends in the Vega archipelago (Bjerck 1989) or Hauglid's study of the preboreal in the Salten region (Hauglid 1993)). Combined with the fact that minimal development-led excavation of Stone Age sites have taken place in the southern sector of Arctic Norway, and that most research excavations occurred prior to modern standards, delimiting the study area to northern Troms and Finnmark has been a necessary and legitimate action to ensure a sufficiently large, resolved and coherent dataset.

The focus in my project are the coastal areas. This is where the majority of the sites are located for all periods covered, indicating that the population was indeed predominantly coastal. It has been a concern to what extent this very distinct distribution of sites was a result of archaeological activity concentrating along the coast, but a recent research project focusing specifically on the inland in Troms and Finnmark (Skandfer et al. in press) does not support this, strengthening the argument for a predominantly maritime orientation of the Stone Age populations in the area. I provide a brief integration of important interior/coastal dynamics [Section 2.1 and 4.4.2], yet my main concern here is directed at human/environmental relations in the coastal biome of Arctic Norway. Further strategic reasons for this delimitation, which includes data quality and methodological requirements, are discussed in [Section 4]. Detailed data analysis is provided for several regions of various scales, including the entirety of Troms and Finnmark counties, yet the main data catchment area for the in-depth case studies belongs to the coastal area of NW Arctic Norway (Fig 1).

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[1] For extended project information see the following links:
https://prosjektbanken.forskningsradet.no/#/project/NFR/261760/Sprak=en
https://en.uit.no/forskning/forskningsgrupper/sub?p_document_id=419451&sub_id=445739

[2] Original wording of the PhD-position call (advertisement ref. 2015/25555), now unavailable online.

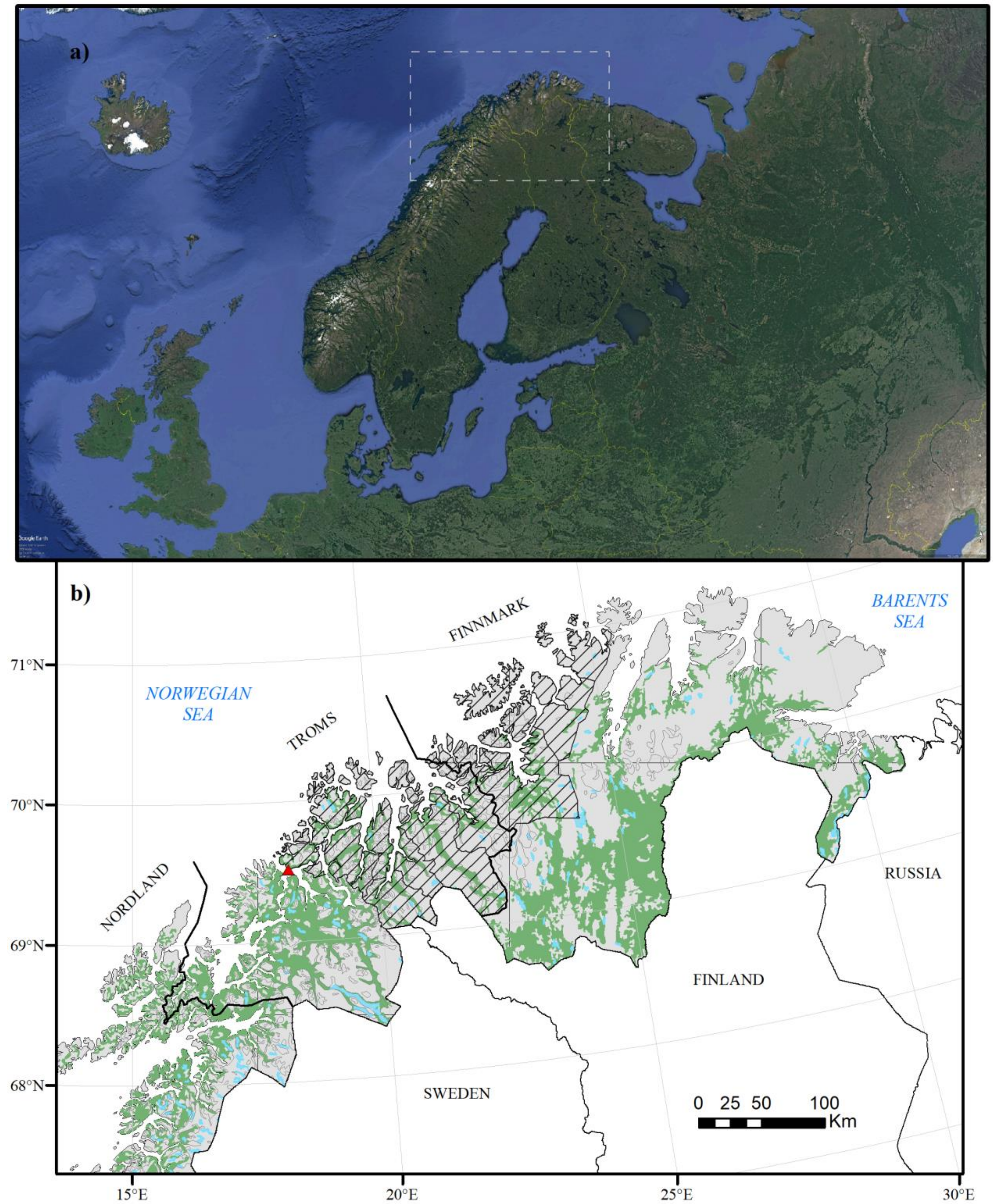

Figure 2 Map of study area. A) Satellite photo of northern Europe. Google Earth. B) Map of Arctic Norway displaying counties and national borders of adjacent countries. The overall study area encompasses Troms and Finnmark counties. Hatched area corresponds to the primary study area, the NW Arctic coast, from which the majority of dates stem. Red triangle marks the location of the Malangen fjord. Map data by Kartverket.

The overall time period of interest to the *Stone Age Demographics* project group has been the 10.000-year interval between ~12.000 and ~2000 cal BP when prehistoric, hunter-gatherer lifeways dominated present day Arctic Norway, roughly corresponding to the presence of lithic tool industries in the area (Damm et al 2018:1). This also forms the macro-scale temporal bounds of this study. As is made clear in the discussion of research design [Section 3], it has been necessary to start out with a broad time interval as the basis for pattern recognition of significant trends and events that could be studied in more detailed as case studies. The 9500-year time interval of this study hence primarily delimits the relevant extent of the data collection of radiocarbon dates, which forms the primary data source in my case studies. The main emphasis of the cases is put on the Late Stone Age and initial Early Metal Period (7000-3000 cal BP) given the better quality of the available data and the multitude of demographical variability and socioecological transformations identified in this particular interval. This is in accordance with the overall research project. That being said, important results are presented and discussed both of earlier and later periods (e.g. in articles 1 and 3 with discussions of trends at the upper and lower end of the time scale respectively). Another reason for prioritizing the Late Stone Age is to be found in the research history of northern Fennoscandian archaeology. While significant antecedent work has been done within human ecological and environmentally focused research, this has mostly been directed at the Early Stone Age. This chronological contrast provided ample opportunity to extend prior efforts and perspectives into an archaeological period dominated by sociocultural perspectives. The choice of spatiotemporal boundaries of the study area and the time interval is also strengthened by the Late Stone Age archaeological record providing a larger and richer source of information, making it more amenable to the research questions of the current thesis.

1.3 Overall ambition of thesis and main research objectives

In the broadest sense, the aim of this project is "*to establish large-scale human ecodynamic trends among prehistoric populations of Holocene Arctic Norway"*. More specifically, the project is geared towards five research objectives that are integral to the entire project. As this is an article-based dissertation, the individual papers address these objectives more or less directly through more operationalized formulations. The relation between the overall ambition and actual studies are discussed in [Section 3.Research design].

The overall research objectives are:

1. Investigate the human ecodynamic trends of Holocene Arctic Norway: Specifically investigate relative population size and how it relates to environmental factors.

Operationalized:

a. Reconstruct relative population size changes through time
b. Compare with relevant palaeoenvironmental records
c. Provide detailed case studies of human adaptive responses to ecological change
d. Establish middle-range causal mechanisms connecting macro-scale climate forcing with micro-scale human risk reduction strategies, by way of aggregated demographic, technological and ecological effects.
e. Track the evolution of maritime adaptation in the region.

Although the main objective is to establish large-scale human ecodynamics trends, a highly important, secondary objective is to develop middle-range human ecodynamic mechanisms. By this is meant trying to establish the causal pathways responsible for mediating large-scale environmental variability up through local ecological food webs and affecting human demographic and adaptive strategies. This also has to do with the incompleteness of purely mechanistic explanations of large-scale trends, as they should be grounded in multi-scalar analysis whenever possible. Consequently, I have defined my purpose as making linkages between both the upper and lower spectrum of the scale I am working in, as I believe any contribution should aim at stating the relevance for neighboring scales. This is foundational to my project, as advancing human ecodynamic research both requires and facilitates a particular focus on scalability, explored in [Section 3.3.Scalability as structure].

The title of this dissertation is "*Human ecodynamics of Stone Age Arctic Norway: Developing middle-range causal linkages between climate forcing, demography and technological responses*". Although it may create the expectation that all variables of human ecodynamics and the entire Stone Age period will be accounted for, that is very much not the case. From the outset, this work is limited to the "ecology" of past human populations in prehistoric Arctic Norway while drawing on comparative insights from other circumpolar populations. Ecology is here mostly applied in the sense of "human ecology" very broadly defined as the study of the relationship between humans and their natural, social, and built environments (cf. Bates 2012).

Primary focus is directed at the Late Stone Age and initial Early Metal Age (7000-3000 cal BP), corresponding in large part to the palaeoenvironmental and geological time unit of the mid-Holocene. The Early Stone Age (11.500-7000 cal BP) and the Early Metal Age (4000-2000 cal BP) are touched upon in this dissertation, but I see my main contribution as further developing the archaeology and population ecology of the mid-Holocene. I state this at the very beginning, as I have not been so concerned with established chronological or typological frames of reference, but instead aimed at integrating the archaeology and human palaeodemography with the conditions set by the natural environment. The mid-Holocene as well as the transition into the Late Holocene increasingly came to my attention throughout my work for a number of reasons. First, because of the greater archaeological resolution of this period and the many major cultural transformations occurring in this 4000 year timespan from 7000-3000 cal BP, but also because the environmental conditions of the mid-Holocene and ensuing correspondence between natural and cultural developmental trends provided ideal case studies for the research objectives explored here.

The particular maritime focus grew out of the need to more systematically conceptualize the Stone Age populations in Norway within a *maritime* adaptive framework. The comparative component of Circumpolar maritime groups has been only weakly present in the local research agenda, with a few exceptions (see Hood 1995; Renouf 1984). My project has therefore taken upon itself to explore the maritime characteristics of the human ecodynamics more in-depth. Whereas most areas on the globe with deep-time human presence track cultural development as a move from the Palaeolithic to the Neolithic, the very concept of the northern European "Mesolithic" was developed to encompass the significant shift towards aquatic adaptive strategies, epitomized by shell-midden sites and the proliferation of boats, nets and fishing technology (Bailey and Milner 2002:7). However, this Mesolithic adaptive shift and its continued evolution throughout the Holocene has mostly been treated as a culture-historical trend within Scandinavian archaeology, rather than conceptualized within a coherent analytical framework emphasizing *adaptive features* (cf. Bjerck 2009). Contributing to such a rethinking of maritime adaptive strategies is a major motivation for this project. The Norwegian coastline is one of the very few places on Earth "where the Preboreal coastlines are situated above the present sea level" (Breivik 2014:1478). Add to that, the coastal Norwegian archaeological record displays unique quantities of and consistencies in Early and Mid-Holocene data (Glørstad et al.

2020:129). This provides one of few suitable areas to explore deep-time human ecodynamics of maritime-adapted populations.

It is already an established view that maritime adaptations are capable of sustaining cultural properties among hunter-gatherers that otherwise tend to be associated with agricultural populations (Fitzhugh 1975:38; see also; Yesner et al. 1980 with comments). Recently, however, there has increasing interest in understanding the importance and evolutionary history of aquatic and later, maritime, adaptations to the human species at large. This has been induced by several strands of research: 1) systematic exploitation of coastal resources is now considered to be rooted in the Middle Stone Age of sub-Saharan Africa, with distinctly coastal adaptations being linked to the emergence of bio-culturally modern *Homo sapiens* (Marean 2014). 2) Somewhat surprisingly, the evidence is becoming increasingly clear that aquatic resource exploitation has been a driving force in the initial spread of ceramic technology among foragers across late Pleistocene/Early Holocene Eurasia - a trait otherwise associated with agricultural Neolithic societies. The observation that ceramic and other "Neolithic" traits have a much deeper history independent of agriculture has been framed as the "Aquatic Neolithic" (Gibbs and Jordan 2016; Gibbs et al. 2017). These developments provide additional reasons to rethink the quintessentially maritime population of prehistoric Arctic Norway within a broader adaptive and human ecodynamic framework.

1.4 Analytical framework

The theoretical foundation for the research questions posed in the individual papers, as well as the premises and concepts I draw on, have been given some attention in publication. However, these theoretical underpinnings could not be properly fleshed out given the format of scientific papers. I here take the opportunity to engage with foundational issues of theory-derived hypotheses and concepts. This is necessary as it forms the crucial link among the individual papers, but also in integrating them into the coherence of this dissertation.

This project is situated within the framework of **"human ecodynamics"** (henceforth H.E.). As this is a brand of fairly recent origin, possibly unfamiliar to readers outside what has become a Pacific Northwest-centered phenomenon, some initial clarification is desirable. Human ecodynamic research essentially concerns "the dynamic integration and co-evolution of human and natural systems, or socioecosystems" (Fitzhugh et al. 2019:1077). Even though it should be unnecessary to point out that human/nature-dichotomies are useless analytical categories in my and human ecodynamic research in general, the very term "human ecodynamic" might, by connotation, give the impression of wanting to uphold this divide. To the contrary, "Those who study human ecodynamics reject the notion that humans should be considered external to the environments in which they live and have lived for millennia" (Fitzhugh et al. 2019:1077). Thus, H.E. continues a well-established tradition in archaeology that stresses the inseparable interconnection of human history with the push- and pull factors of the total ecosystem humans by definition are a constituent part of. This is a realization going back at least to the programmatic statements of (Steward 1990 [1955]), yet with roots back to the antiquarian origin of archaeology (Barnard 2014). I would therefore like to reiterate a defining characteristic of the approach applied here, in that "H.E. should be viewed as a subject of study and not a paradigm" (Fitzhugh et al. 2019:1088). The ecology of humans and their culture has also become fully ingrained in the minds of any scholar of past human and environmental systems. An important realization from decades of empirical investigations is that pristine environments completely devoid of human impacts are highly unusual – if existing at all, as evidenced for instance by Roman-Era lead pollution in Greenlandic ice cores (McConnell et al. 2018) and early industrial era aerosol pollution in Antarctica (McConnell et al. 2014). What distinguishes current and early attempts at integrating human cultural evolution with its environmental setting are the implications of the marvelous technical and scientific advances taking place over the last 20 years or so. Prior to these advances, the prospect of investigating human/environment interactions were mostly limited to the conceptual realm. Today, it is possible to amass great quantities of empirical data and reconstruct a range of past human and environmental conditions, and thus make true progress in the diverse field that is H.E..

In establishing the relevance and justification of this thesis, one may easily ask whether its environmental focus is a response to the contemporary public debate, merely a sign of the times so to speak, and thus, reducible to sociological variables. Although H.E. research is increasingly becoming conscientious about current affairs - occasionally with the explicit ambition of linking past and future states for constructive mitigation of e.g. climate change - this is expressively not my ambition. However, if such should somehow occur, that is a fortunate side effect. Indeed, I state similar hopes throughout my papers. As made clear in [Section 2.Background], my curiosity grew out of a particular research historical background and the ambition of contributing to the advancement of issues absolutely fundamental to the archaeological discipline.

Within the broad scope of H.E. research this thesis homes in on palaeodemography as the main variable to be explored. Yet, “demography” and “population” are not self-evident concepts in the study of past human societies. In dealing with the remnants of extinct populations, archaeology cannot observe past societies or their inhabitants directly, thereby undercutting the very prospect of truly *demographic* studies from the onset. This is slightly contradictory and requires some explanation. Demography, strictly defined, is the “statistical study of human populations, especially with reference to size and density, distribution, and vital statistics (births, marriages, deaths, etc.)” (Britannica 2016). Attempts have been made to reconstruct vital statistics and age pyramid distributions among non-living populations from skeletal remains (Muriel 2014; Tverdý 2016; Ubelaker and Pap 2009; cf. Bocquet-Appel 2008). Such studies have been restricted to favorable, (mostly) historic cases (Bocquet-Appel and Masset 1982; cf. Cramon-Taubadel et al. 2013). By and large, archaeology can only indirectly access the demography of past populations by proxy, rendering “demography” strictly defined inaccessible. Instead, when talking of palaeodemography, archaeology is actually dealing with the study of change in either relative or absolute population *size* (reviewed in (Milner et al. 2018)), and increasingly, population size changes as an expression of long-term adaptive fitness (Tallavaara and Jørgensen in press). As such, we study populations indirectly by inferring population level demographic properties from their effects on more readily available data sources, such as technology, settlement and mobility patterns, adaptive strategies, zooarchaeological deposits etc.

In the current case, I rely on the biological definition of a “population” as all same-species organisms inhabiting a discreet geographical area and that have the capability of interbreeding. In practice, it is difficult to separate adjacent populations, be it past or present. Mobility may result in individuals from separate populations being able to interbreed. Considering the successful colonization of all continents and the adaptive flexibility displayed by human populations, this becomes even more problematic. Consequently, human populations are mostly a conceptual construct depending on the scale of the research question at hand, giving rise to inclusive concepts such as the “metapopulation” (Hanski and Gaggiotti 2004). In archaeology, this is all the more difficult to discern, as we do not know the biological and cultural inheritance structures that would have made up any given population in the past. Consequently, when talking of populations in this thesis, I refer to whatever group of individuals is encompassed by the geographical scale currently employed in discussion.

Given these limitations, a reasonable response would be to question the foundation of the recent archaeological interest in palaeodemography, as well as the point of this thesis: Why study palaeodemography if it is mostly a conceptual construct? My reply would be that demography is both a valid and important topic of archaeological scrutiny, as it is one of the most essential variables in any integrated human system. In fact, I find it hard to come up with meaningful exceptions to the rule that most aspects of the human past were significantly influenced by population level demography. Population level demography is the aggregated expression of nearly everything we care about as archaeologists – permeating everything from community structure, economy, technology, settlement and mobility patterns, the prospects for labor division and specialization with associated impacts on gender-relations, warfare, networks, migration, ideology etc.

As will become apparent throughout this document, I have taken on a rather "processualist" approach in my research. By this I mean nothing more (or less) than that my research interests are directed at generalizable properties of the past, such as processes and their causes. To me, archaeology is fundamentally about understanding general mechanisms and getting at the ultimate causes of change (as discussed in [section 2.2-2.3]). This is in contrast to research directed at reconstructing particular states of past affairs – although this is closer to the popular conception of what archaeology is about. Without any strong programmatic commitments, I therefore view archaeology as anthropology and not history, sensu Binford (1962). However, working towards answers to HOW and WHY questions require the prior establishment of the WHAT, the WHERE and the WHEN. In practice, this implies the need for exploratory research to form the basis on which explanatory research may progress [section 3]. In my research, I have tried to combine these considerations so as to provide the fullest account of these interrogative words within the confines of my project and what is allowed by current data.

Throughout this thesis, "maritime" is used as concept, particularly in concert with "adaptation". This may trigger some confusion as it is commonly associated with the adjective of "things connected to the sea". As uses of both "aquatic", "coastal" and "maritime" adaptations verse the literature, it can be slightly confusing what components of aquatic ecosystems actually are included and excluded in the carious concepts – reviewed in (Erlandson 2001:299; cf. Workman and McCartney 1998). Although "maritime adaptation" is a highly inclusive concept, its main purpose is separating the exploitation of saltwater resources at the exclusion of freshwater systems and lakes – the latter two being implied by coastal and aquatic adaptations. Binford, for instance, has been using "aquatic adaptations" as a catch-all for both marine contexts and freshwater systems (Binford 1990, 2001:167). Here, however, "maritime" is used as part of the North American archaeological tradition going back at least to the 1970´s, in which the concept of "maritime adaptation" has become standard jargon. This grew out of the initial work by William Fitzhugh (1975:344) when trying to classify ecosystem-specific adaptive strategies and separating maritime from riverine adaptations, amongst other types. Along with other early works, (e.g. Clark 1979; Yesner 1980), these scholars were looking for an alternative to the terrestrially focused research agenda at the time that might be more fitting to the study of prehistoric people engaged with coastal landscapes (see also; Bjerck and Zangrando 2016:5). Maritime adaptations, in this understanding, include any form of dependency and interaction with coastal resources that is accommodated through time for making a livelihood. Attempts have been made to define the concept more strictly, such as the proposal that for maritime adaptations to occur, there needs to be a >50% reliance on marine calories/protein in the diet (Yesner 1980:728). Yet common usage of the concept has become less operationalized in terms of diet due to the difficulty of calculating such measures reliably. The use of the concept has therefore shifted to the overall adaptive features of the group in question. This is how I use the term.

Admittedly, the term “coastal adaptation” may in many cases be interchangeable with that of “maritime adaptations”. The separation between freshwater and saltwater adaptive strategies may also give too much of analytical leeway, particularly when considering that maritime resource exploitation may have originated in riverine economies (Vasil’evskii et al. 1998). However, one way of sorting this is to distinguish the categories maritime and coastal. "Coastal" can be a descriptor for relatively constrained littoral activities - such as those of early modern humans and shellfish collectors sensu Marean (2014). "Maritime" could be defined as subsuming both coastal/littoral activities and offshore activities conducted with boats and other specialized technology. As such, maritime adaptations broadly include all potential aquatic components spanning the tidal zone/open ocean spectrum: from foraging for shells in the intertidal zone, trap fishing and clam collecting in estuaries, to dedicated boat fishing and sea mammal hunting in fjords, archipelagos and pelagic resource exploitation on the open ocean. Additionally, the exploitation of seabird colonies for meat, eggs and down could also be considered “maritime”, being part of the nutrient cycling in marine/coastal ecosystems. It is therefore a rather broad concept, suitable to describe a wide range of human ecodynamic and adaptive scenarios that are connected by the engagement with saltwater ecosystems. Despite such inclusiveness running the risk of becoming analytically ineffective, one gains the conceptual flexibility that, arguably, reflects more realistically the adaptive strategies that have existed along prehistoric coastlines.

In this context, I have followed the North American archaeological tradition as it is most in line with the analytical framework that the thesis is positioned within. Also, I have done so given the ambition of seeing the human ecodynamic trends in the study area from a water-based, rather than land-based, perspective (cf. Bjerck 2017; Reid 2015). If nothing else, I believe such is legitimate given consistent use of the concept. By the most commonly used standards for defining societies as maritime or not, the deciding factor is that of going out on open water by boats and utilizing specialized fishing/hunting gear, contra that of foraging of littoral resources - reviewed in (Erlandson 2001:299–300). By this mark there can be no question as to the maritime character of the prehistoric population of Arctic Norway, evidenced both by a colonization route and settlement pattern requiring boat technology.

A related concept of importance to the current thesis is “maritime intensification”. “Intensification” (of any sort, be it economic or otherwise) can be a problematic term given its varied and potentially contradictory uses, as reviewed by Morgan (2015:168): “The meaning of the term itself became conflated with both a strict Boserupian definition that entails declining foraging efficiency (hereafter “intensification sensu stricto [s.s.]”) or alternatively as any means of increasing productivity (e.g., diversification, specialization, innovation), including those that ostensibly increased efficiency (hereafter “intensification sensu lato [s.l.]”)”. The concept, as used in the current thesis, is of the latter sort. As stated in paper 4:

> ““Intensification” is here used in the *sensu lato*, systemic sense, of any input made to an economic system with the aim/result of increasing returns (Tainter 2006:61). Intensification strictly defined entails increased labor efforts to maintain constant returns, typically by targeting lower-ranked and more time-consuming resources (Morgan 2015). Comparatively, systemic intensification does not have to result in a shift in the relative importance of e.g. different foodstuffs or an increased reliance on lower-ranked resources. It rather focuses on the total investment costs of a subsistence regime, independent of resource rankings” (Jørgensen 2020:14).

Papers 3 and 4 deal specifically with the concept and prospects of empirically identifying maritime intensification in the local and northern Fennoscandian archaeological record. Both papers spend some time pondering the issue of how to conceptualize a rearrangement of the maritime economy of an already highly maritime adapted population (Jørgensen et al. 2020:2-3,9; Jørgensen 2020:33-42). The people occupying the Norwegian coastline have been dependent upon maritime resources throughout the entire settlement history of the area. Colonizing the area itself required complex maritime technologies. If already maritime, then how can one possibly talk of maritime "intensification" during the mid-Holocene? Maritime "specialization" may offer a more compelling term, encapsulating important aspects of the *sensu lato* definition of maritime intensification: implying increased efforts and investment costs going into maritime subsistence practices, and/or a narrowing of diet breath, all the while not having to invoke declining foraging efficiencies within the potentially more restricted range of resources used. In fact, much of the discussion presented in paper 4 consists in establishing the potential positive (that is, increased foraging efficiency) potentially gained by such specialization/intensification – claiming that specialized maritime equipment (e.g. slate tools) can act as "enabling technologies" in facilitating *sensu lato* intensification. In the introductory chapter, however, I have mainly stuck with the concept of specialization over that of intensification.

Beyond concepts of the "maritime", "adaptation" is equally in need of clarification. The current thesis makes frequent use of the term, which is justified by the longue durée aspirations of this work. However, "adaption" implies permanent change to the biology, technology, economy etc of a population. That is, something which is reproduced through genetic or cultural inheritance across generations. This contrasts with the more immediate "coping mechanisms" that arise in the face of particular needs (cf. Dincauze 2000:75–77). What may start out as a minor adjustment to the adaptive strategy of a population through immediate coping mechanisms, may eventually feedback into a regime shift of the adaptive strategy – given sufficient stressor longevity, as well as the reproducibility and success rate of the coping response (e.g. Fitzhugh 2001). This distinction is all the more important in the study of human populations, given the extensiveness of human adaptive flexibility. Although most vertebrate species may be expected to display various levels of on-the-spot coping behavior in the face of risk or danger, humans display a disproportional amount of coping flexibility beyond what is proscribed by genetic inheritance. Importantly, the concepts should be seen as differently scaled expressions of what ultimately is the same thing: adjustments to changing externalities to mitigate risk and/or increase some measure of good, e.g. adaptive fitness. Coping mechanisms are often referred to as "risk mitigation/reduction strategies" in the anthropological and archaeological literature (e.g. Halstead and O'Shea 1989; Minc and Smith 1989). I have tried to comply with this terminology.

My papers are mostly concerned with the longer-term effects of environmental change on human populations – thus focus is more often directed at adaptations than at coping mechanisms. The use of the term "adaptation" is accordingly given preference. Yet, in line with the ambition of contributing to the analytical middle-range, it has been important to attempt a coupling of the various scales of adaptation. This is most clearly expressed in paper 2, which specifically concerns the shorter-scale coping mechanisms employed during the *Gressbakken phase* (4200-3500 cal BP) in the face of environmental perturbations and ecological restructuration. What is more, paper 4 analyzes how an initial coping response to environmental shifts was taken advantage of, and became a long-lasting technological tradition, reproduced as part of a highly successful adaptive strategy.

2 Background

As this thesis compiles, compares, and integrates temporal data from a multitude of disciplines often adhering to specific scales and classificatory schemes adapted to particular research interests, the thesis necessarily has to juggle a set of temporal concepts. In an attempt at reducing the complexity and likely confusion of these concepts, a comparison of the relevant chronologies and related concepts are presented in (Fig.2). Although the main focus is on the archaeology and demography of Stone Age Arctic Norway (with its specific chronology), regional comparison and synthesis with other regions necessitate linking this with broader archaeological chronologies of Scandinavia/northern Europe. However, throughout this project, the dominant chronology is that of the geological and palaeoenvironmental time units of the Holocene. This is a more robust and empirically well-founded chronology more useful for current purposes than local culture-history chronologies. This is justified given the Human Ecodynamic research objectives of this thesis, with the expressed intent of integrating human demography and adaptive strategies with ecological and environmental parameters. In order to foster compatibility between archaeological and environmental data, all dates are reported as calibrated years before present (cal BP 1950).

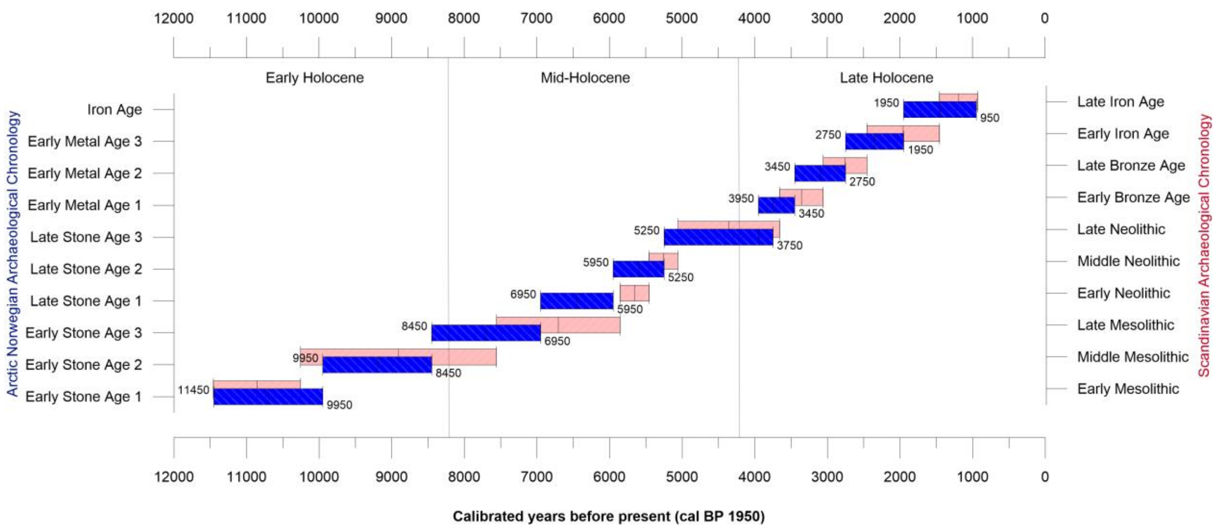

Figure 3 Chronological comparison of local (Hesjedal et al. 2009:379) and regional (Mischka et al. 2014) archaeological schemes, in relation to the overall geological/palaeoenvironmental Holocene chronology (Walker et al. 2012).

2.1 Why ask these questions? Prior research status

The overall ambition and research objectives of this thesis did not emerge *ad nihil*. Instead, they were constructed with the aim of progressing the state of the art within the field, and necessarily had to build upon existing knowledge. This way, my work exemplifies the cumulative nature of research. While accumulating and synthesizing existing data is fundamental, my research also contributes multiple novelties to the archaeology of Arctic Norway and Circumpolar human ecodynamics in general.

It is necessary to provide in-depth explication of the setting and positioning of my work. Consequently, I here present the local and regional conditions that have shaped my research agenda. Although the focus of this section is primarily directed at northern Norwegian archaeology for that very reason, I have tried to make relevant linkages to research trends in the adjacent areas of northern Fennoscandia, but also to important trends within the archaeological discipline at large.

I try to establish the links between the main study area and adjoining areas for culture historical synthesis. Given the mainly maritime scope of this thesis, it is fruitful to account for properties of the coastal archaeological record further south along the Norwegian coastline (Nordland County), as it is disproportionally underinvestigated. This is given priority in subsequent discussion [Section 4.4.2] over conjoining inland areas, such as interior northern Finland and Sweden, not because such areas are unimportant, but because my work is more strongly directed at coastal human ecodynamics. Note however, that efforts have been made in this section to integrate current knowledge of interior trends in present day northern Finland and Sweden, as these areas likely were part of supra-regional socioecological networks in the past, where movement between coast and inland would have been important.

2.1.1 Demographically related research trends

An important inducement to my work is that the environmental and ecological aspects of the Arctic Norwegian Stone Age had not previously been reviewed in detail. Little has been done, and mostly subject to informal and native language discussions, less available to the international community (Damm et al. 2019:3). The most notable local exceptions are zooarchaeological analyses (Hodgetts 2010; Renouf 1989). Palaeodemography as a systematic topic is new to north Norwegian archaeology, particularly concerning the population level. In fact, the topic has mostly been relegated to popularized historical lexica providing sweeping summations of the development “from the Ice Age to the Industrial Era”, often concerned with the geographical origin of “ancestors” (Drivenes et al. 1994:85), as well as the occasional synthetic remarks in excavation reports. The dominant population historical tale suggests a steady increase as sedentism became gradually more cemented in the Late Stone Age up until high-mobility lifeways reemerged during the first part of the Early Metal Age (Holdberg and Røskaft 2015:45; Olsen 1984:207; see also Bratrein 1989; Sandmo et al. 1994).

The population-historical understanding of Arctic Norwegian prehistory in the academic context has mainly consisted in fragmented period descriptions characterized by higher or lower levels of archaeological visibility. The way discussions of “demography” have fundamentally been related to archaeological visibility reflect the prevalence of Stone Age dwelling features (houses) on the modern surface. As houses have been the main unit of investigation throughout the local research history, so have demographic deliberations dealt with household- and site scale issues.

In the following, I provide a summarized overview of “demographically related” trends in northern Fennoscandian archaeological research prior to this work, with a main emphasis on Norwegian research history.

Early Holocene (Early Stone Age [ESA]) trends

Demographically related research into the Early Stone Age conditions (12000-7000 cal BP) has emphasized the high mobility-lifestyle of the pioneering and subsequent Mesolithic periods, characterized by presumably small groups of people leaving markedly fewer material and structural traces than in succeeding periods (Bjerck 2009; Blankholm 2018a:56; Hesjedal et al. 2009:391; Kleppe 2014). Such has been inferred from a rather homogeneous archaeological record along the entire Norwegian coast, in terms of lithic tool types, minor site size and the infrequency of dwelling structures. A differentiation of the so-called "Komsa culture" was early on asserted between larger settlements in the inner fjords and more ephemeral sites on the outer coast, assuming that the larger assemblages at the inner fjord sites reflected longer occupation and/or larger populations (Odner 1964:118). This was later revised by (Bjerck 1989) when applying the Binfordian settlement model (Binford 1980) to the coast of Nordland County. Aided by more precise chronology following the advent of radiometric dating, Bjerck (1989:25) argued for residential bases and primary occupation on the outer coast during the middle Mesolithic, with a shift towards residential bases on the mainland with outer coastal satellite camps in the late Mesolithic. This model has become the dominant view in Arctic Norwegian Stone Age archaeology (e.g. applied to Varanger by (Grydeland 2000)) although mostly as an implicit assumption. Mesolithic settlement patterns and mobility have seen less attention since then (cf. Blankholm 2008:96). However, in the broader context of northern Fennoscandia, long-term patterns of settlement and subsistence change have been reconstructed for the interior of northernmost Finland (Halinen 2005; Kankaanpää and Rankama 2005; cf. Matiskainen 1989), while syntheses of early Holocene interior sites in Sweden are provided in (Bergman et al. 2004; Östlund 2018; cf. Möller et al. 2013). Keep in mind though, that due to isostatic uplift, some of the early Mesolithic Swedish sites were located in an archipelago in the Ancylus Lake at the time of occupation.

Special attention has been devoted to colonization events and people movement across the northern Fennoscandian landmass. We now see Arctic Norway as having been colonized by different populations coming from two directions: an Ahrensburgian-related population moving along the coast from the southwest and the Swiderian related population moving through the inland from the southeast (see also Kleppe 2014, 2018). The relationship between and chronological priority of these colonizing groups is still a matter of contention. Historically, there has been a tendency by Norwegian scholars to assume colonization from the coast to the inland. The Norwegian default scenario became complicated, however, by the discovery of a technologically distinctive site in northern Finland - Sujala – which has been attributed to a colonizing group from the east related to the Post-Swiderian tradition of pressure blade lithic technology (Rankama and Kankaanpää 2008; Kankaanpää and Rankama 2011; Rankama and Kankaanpää 2018). An extensive literature has grown concerning the spread of pressure blade lithics identified at Sujala (Damlien 2016; Kankaanpää and Rankama 2011; Rankama and Kankaanpää 2008; Sørensen et al. 2013; cf. Kleppe 2014). Although previously not integrated into the local synthetic literature, aDNA (Kashuba et al. 2019; cf. Günther et al. 2018) and dynamic technological results seem to support population movement and admixture along with the spread of pressure blade lithic technology across Fennoscandia, at ca. 10.000 cal BP. Although significantly later than the initial Ahrensburgian-related coastal colonization route, it is more in line with the southeastern colonization route of northern Fennoscandia, often favored by Finnish scholars. It has also been suggested that an even earlier colonization event into present day eastern Finnmark may have followed an eastern route (Kleppe 2018:13).

Typological similarities have been argued to indicate that pioneering groups practiced extensive long-distance contacts across coastal and interior landscapes (Hertell and Tallavaara 2011). However, later Mesolithic differentiation in lithic tool types and raw material use led to frequent assumptions of distinct populations occupying the Norwegian coast and the northern Fennoscandian interior (e.g. Rankama 2003), and/or areas connected to the coast in the Bothian Bay (Damm 2006:197). The existence of distinct groups occupying the Norwegian coast and the adjacent inland has, however, been questioned by others (Hood 2012:128).

The coast/inland contrasts between the two colonizing populations is simply a newer twist on a theme that has been central in discussions of Mesolithic settlement. Olsen (1994:36-39) suggested that the early Mesolithic populations in Arctic Norway were restricted to the early post-glacial coastal strip. The interior tentatively became subject to seasonal exploitation during the middle Mesolithic, while fully integrated interior adaptations was not to have taken place until the late Mesolithic. Differences in coastal and interior raw material use have been used to suggest the presence of different spatially bound and separately adapted populations. Some have argued for more direct mobility between the Norwegian coast and the Finnish interior during the middle and late Mesolithic, as suggested by the presence of coastal-source cherts in the interior (Halinen 2005:89; Manninen 2009:105–6). For instance, Halinen (2005:88–90) suggested that the Enontekiö region, dominated by quartz use, was colonized from southern Finland, while the Inari region was colonized from the Varangerfjord coast, given the presence of assumed coastal cherts in middle Mesolithic sites. However, problematic aspects of a coastal population moving into the interior have also been emphasized, given the supposedly cognitive bounds of environmentally specific adaptations and raw material use. This is pointedly expressed in Rankama´s claim that:

> "If resources were the key issue, we could easily imagine hunter-fisher-gatherers moving between the coast and the inland with little difficulty, simply shifting their economic focus from one group of animals to another, for example on a seasonal basis – and examples of this type of subsistence pattern abound in the ethnographic literature. In my view the situation in Mesolithic coastal north Norway and northern Finnish Lapland is different, however. Here we are dealing with two separate well established populations and types of adaptation, one maritime and one geared towards inland resources, and we have to decide which was the more likely to have colonized a new inland area that had become available" (Rankama 2003:44).

While not explicitly framed in terms of palaeodemography, coast/inland group relations across northern Fennoscandia has been an important research topic. A whole number of papers that touch on coast/inland relations of northern Fennoscandia can be found in (Larsson [ed.] 1996; cf. Schulz 1996:29). Havas (1999:119) summarized existing research efforts as a set of tentative land use models of the interior of Finnmark and northern Finland, detailing the coast-inland mobility and settlement patterns of the early Holocene. Important antecedent and associated studies in this regard include (Basso 2007; Hood and Olsen 1988; Hood 2012; Simonsen 1963, 1965, 1985). Skandfer (2003:393) also reviewed the distribution of early comb ware and bifacial points across northern Fennoscandia in terms of their cultural significance to group formation and coast/inland interactions. An extensive, Holocene-wide, synthesis of the archaeology and human ecology of interior Arctic Norway is currently underway, providing important correction to the coastal bias of prior research (Skandfer et al. in press).

Human demographic variables have rarely been the object of scrutiny or formed part of explanatory accounts of the Mesolithic archaeological record. In cases of explicit mentioning, associated demographic variables, such as population pressure, have rather been discounted as explanatory ineffective given the assumption of minor groups of people facing a situation of inexhaustible resources during the early Mesolithic (Grydeland 2005:30). One of very few direct treatments of Mesolithic population trends argued for a drastic reduction in human presence on the eastern coast of Arctic Norway related to a shift towards inland settlements at the transition to the mid-Holocene (Grydeland 2000:31–35). This was argued to be the result of a new colonizing population entering from the interior of Finland, as indicated by coastal lithic assemblages dominated by quartz

(Grydeland 2000:44). Otherwise, Hagen (2011) and Manninen (2014) both argued that the 8200 cal BP cooling event affected coastal populations and led to interior-oriented adaptive adjustments, with Manninen and Knutsson (2014) arguing that lithic raw material diversification was an adaptive strategy in this context.

Finally, from approximately 9000 cal BP semi-subterranean dwelling features that are still visible on the modern surface emerge at Arctic Norwegian coastal sites and have been argued to signal decreased mobility (Schanche 1988:164), which is often associated with elevated population numbers. It has also been taken to express a settlement pattern mostly in accordance with Bjerck´s model, with e.g. the Tønsnes site in Tromsø being indicative of a co-residential winter village (Gjerde and Skandfer 2018; cf. Blankholm 2018:58). Since being alluded to in (Schanche 1988:136), the presence and increasingly old age of more permanent dwelling features is still solidifying (e.g. Bjerck et al. 2012; Fretheim et al. 2018; Gjerde and Hole 2013; Skandfer et al. 2010). The demographic implication of these trends being that of larger group sizes, following increased site permanence and reduced mobility from the mid/late Mesolithic transition.

Mid-Holocene (Late Stone Age [LSA]) trends

The increasing accumulation of culture-layers in the initial phase of the mid-Holocene (~7500 cal BP) has been pointed to as indicating larger population gatherings at more permanent sites (Hesjedal et al. 2009:393). Clusters of dwelling features on fossil beach ridges have been proposed from 7500 cal. BP (see Hesjedal et al. 1996:100,152). The dwelling features are often assumed to develop from small and shallow depressions into large and deep depressions with significant mounds and middens during the mid-Holocene (Hood, Helskog, et al. in press; Fretheim et al. 2018; Olsen 1994:38). It has been proposed that both the coast and interior were settled by the time of the ESA/LSA transition (7000 cal BP), with corresponding territories covering the entire landmass (Olsen 1994:41), and later (4000 cal BP), the formation of clear social boundaries between coastal and inland groups (Olsen 1994:96). There has been a long tradition of assuming separate coast and inland populations in the LSA. Andreassen (1985:291) suggested the rock art sites of inner Alta fjord acted as a meeting place of differently adapted populations. The argument has been reiterated in various forms, such as the rock art sites acting as aggregation sites in the nucleation phase of a fission/fusion mobility pattern (Damm et al. 2019b; Hood 1988; cf. Gjerde 2010:410). Similarly, arguments have been made of coast/inland populations meeting at interior sites such as Virdnejávri and Čávču on the Alta canyon river (Simonsen 1985:61). More recent work has questioned the reality of distinct coastal/interior populations and of associated territories (Hood 2012:128), and has suggested that during the initial LSA human populations were concentrated on the coast, with only limited signs of activity in inner Finnmark (Hood in press a).

It has also been suggested that co-residential social units evolved in tandem with supposedly "village-like" clusters of multiple (presumably) contemporaneous houses (Gjessing 1955; Holdberg and Røskaft 2015:45; Olsen 1994:38; Simonsen 1965). The merit of the proposed "villages" and larger social units has been a hot topic and sparked the only explicitly demographic debate in the area. The debate has focused on the degree of sedentism and estimates of settlement sizes, particularly during the final LSA phase. It has tended to focus on the household (Andreassen 1985:239; Helskog 1983:150) and site level (Andreassen 1985:245; Helskog 1983:146, 1984:65; Simonsen 1996:120), with the occasional deliberation on the village/community level (Andreassen 1985:247; Schanche 1994:177, 1995:183). The poster-child for this debate has been the Gressbakken phase (4200-3500 cal BP). This is due to the greatly increased visibility of this period, through large and deeply-dug pithouses assumed to host multiple families, also displaying midden accumulation and preserved faunal and osseous material (Schanche 1994; Simonsen 1961). Depending on the assumed number of contemporaneous houses and number of inhabitants per house, population estimates for sites have ranged between 25-400 contemporary individuals at the largest sites and site clusters (Helskog 1984:66; Olsen 1984:200–209; Schanche 1994:172–187; Simonsen 1979:397–404). Consequently, highly disparate social structures (or the lack thereof) have been proposed on the basis of the population estimates, concerning the likelihood of territories, hierarchies, communal housing, sedentism etc. Although mostly a phenomenon discussed for the eastern sector of Arctic Norway, similar arguments have been put forth for western Finnmark when estimating population numbers, settlement patterns and social structure of the final LSA (Andreassen 1985:245; cf. Hesjedal et al. 1996:206-210; Simonsen 1996:120).

Late Holocene (Early Metal Age [EMA] and Iron Age) trends

Drastically reduced settlement indicators have been proposed for the Early Metal Age (3500-2000 cal BP). Less pronounced house types that are more or less unexcavated into the ground are known from this interval – e.g. (Helskog 1983; Johansen and Odner 1968; Hesjedal et al. 1996) – and reviewed in (Hood, Helskog, et al. in press). Yet, regional synthesis of empirical trends has identified lighter settlement structures (possibly tents) leaving few discernable traces to be the dominant dwelling structure, combined with a drastic reduction in the accumulation of culture layers, and increased site specialization. These trends have been taken to indicate increased mobility and assumed fragmentation of social units (Hesjedal et al. 2009:432-3). This also corresponds to intensified inland activity (Hood, Blankholm, et al. in press; Rankama 1986). Regardless, it has not been explicitly stated how such changes relate to population size, i.e. whether it implies population size changes or stable numbers distributed differently.

Some attention has been directed at a seeming cultural dualism in the uptake and use of asbestos-tempered ceramics in northern Fennoscandia, whose distribution in Norway is centered on the Arctic region and with a temporal span of purportedly 4200-2000 cal BP (Andreassen 2002; Jørgensen and Olsen 1988). Social boundaries between separate coastal and interior hunter-gatherers have been inferred from the distribution of ceramic types of the initial EMA in Finnmark, that later broke down following the shared use of ceramic types between the coast and interior (Olsen 1994:129-133). Furthermore, there seems to have been regional differences in ceramic types between the coasts of Finnmark and Nordland/Troms Counties during the late EMA. Recent isotopic and lipid analyses indicate the Nordland/Troms ceramic type is associated with traces of dairy products (Pääkkönen et al. 2018, cf. Pääkkönen et al. 2016). This herald the social, and potentially demographic, change occurring at the time, following the spread of food-producing economies. Agriculture and metallurgy were introduced to the southwestern sector of the north Norwegian coastline during Late Bronze Age/pre-Roman Iron Age (3000-2500 cal BP) (see table 5 in, Sjögren and Arntzen 2013). The former has been ascribed to population influx/migration of Norse agriculturalists (Arntzen 2015; Jørgensen 2010; Sundquist 1999:55). Agriculture was introduced somewhat earlier to the adjacent areas in Sweden and southern Finland, both by a southern route (see Lahtinen et al. 2017). The initial EMA acquaintance with metal objects, and later adoption of metallurgy, is less well established but may have had an eastern rather southern origin among the foraging population in northern Fennoscandia (Nordqvist et al. 2012)

The archaeological visibility of 2000-1000 cal BP is so low that it used to be termed “the empty period” (Schanche 1992). Very few features, sites or diagnostic finds belong to this period, corroborated by a low-visibility habitation technology and near total lack of evidence for inland activities. It has been claimed that what causes the impression of depopulation in this period is the combined effect of high residential mobility with reduced archaeological visibility (including the end to lithic use) and a possible population decline (Schanche 1992:31). This is one of very few instances in which population trends have been explicitly mentioned. However, there is increasing evidence from coastal Finnmark and northern Troms that slab-lined pits acting as production facilities for marine oil refining frequently date to this interval, and these have been argued to indicate economic investments by local foragers targeting Norse trading networks (Nilsen 2017). Nevertheless, there is still a distinct lack of finds in the interior during the first millennium AD (Hood, Blankholm, et al. in press).

2.1.2 Antecedent studies: Climate, ecology and technology

Regardless of palaeodemography being a less explicitly studied topic in the area, the present thesis has multiple antecedents in the wider northern Fennoscandian research tradition that merit brief attention, concerning human ecology, environmental drivers and technological responses.

Fully integrated studies of climate, resource availability and human demography have only seen brief, prior mention in Arctic Norwegian archaeology. The most explicit case is Grydeland´s (2005:38-39) use of temperature reconstructions from Greenland ice cores and Barents Sea marine sediments as a comparative baseline for temporal trends in artifact and settlement distributions. This is possibly the earliest, direct analog in the local context to the methodology employed in this thesis. Otherwise, the impact of major environmental perturbations within the context of Arctic Norwegian archaeology has centered on the effects of the 8.2 KYA cold event and the Storegga tsunami on cultural changes and mobility patterns (Hagen 2011), although the socioecological impact of the Storegga tsunami in the archaeological record has recently been questioned for easternmost Arctic Norway (Blankholm 2018b). The impacts of the 8.2 event across northern Fennoscandia have been investigated in greater detail by (Manninen 2014), who attributes concomitant cultural changes to its cooling effects (further explored in (Manninen et al. 2018)).

Note that demographic fluctuations caused by climate change and resource decline has one very early mention in local research history, when hinted at by Bøe and Nummedal (1936:255). According to Grydeland (2005:39), they "proposed that the "Komsa" people had abandoned Finnmark. This should be due to their total dependence on one species: the seal, which in turn was dependent on cold sea water to survive. Consequently, a warmer climate could be disastrous". However, this is not their actual claim, which is little more than a thought experiment based on poorly substantiated assumptions concerning the potential area of origin for the colonizing population of the Finnmark coast.[3]

[3] "Let us hypothesize. Let us try for a moment to show what an animal like the seal could signify, itself, for a primitive population of hunters. The answer is simple, even for those who have only superficial knowledge of the life of the Eskimos. For them, the Seal is everything. The Seal is roughly for some Eskimo tribes what the Reindeer is for the Lapp, or better still the Caribou for the caribou Indian. Where the pack ice is found, there we find the Seal, and in its tracks, the Eskimo. So, it is not the relative mildness of the climate that is an essential condition for the Eskimo. It is the cold. History will provide us with a striking example. When the Norwegians and Icelanders colonized Greenland, towards the end of the tenth century, they founded two main settlements in the very south of West Greenland: one further north, Vesterbygda, and the other, Østerbygda, near the southern tip of the country. There they continued to live as before, that is, on raising livestock. The sea was open, there was no pack ice, and therefore the region was not habitable for the Eskimos, who resided further north. But when, at the end of the Middle Ages, the climate cooled, the pack ice descended towards the south, along the entire coast, and the Eskimos came with it. They destroyed Vesterbygda around 1350, attacked Østerbygda for the first time in 1379, and they now they hunt the

In contrast to the sporadic and limited attention given to climate-resource-demography issues in northern Norway, Finnish archaeologists have developed a stronger school of H.E research. Besides Manninen´s engagement with the 8200 event, an important, congruent work to this thesis, is the human ecological study of the Tana river drainage area (Rankama 1996). Rankama (1996:2) investigated the correspondence between multi-proxy paleoenvironmental and archaeological data to test the environmental and ecological determinants of human subsistence and settlement patterns. Although demography and human population dynamics was not considered, and the study was restricted to the upper, interior section of the river drainage (Rankama 1996:30), the Tana River is archaeologically and culture-historically important in connecting the northern Finnish interior with the Arctic Norwegian coast. The human ecology and adaptive strategies of the northern Finnish interior, as described by Rankama (1996:824-5), are strongly in line with the results of the coastal-oriented investigations presented in the current thesis. Both demonstrate strong explanatory efficacy of environmental drivers regarding numerous human and cultural variables. These results, as well as the human ecological investigations of the Arctic Norwegian interior (Hood in press), should be considered complementary in reflecting related aspects of northern Fennoscandian adaptive strategies across coastal/terrestrial ecosystems.

Another related study combined environmental, archaeological and biogeographical data from northern Sweden in suggesting a climate and hunting-induced decline of moose population at the mid to late Holocene transition, that again forced an adaptive shift in human interior subsistence strategies (Larsson et al. 2012). This has significant overlap with my own argument for the collapse of the Gressbakken phase in Arctic Norway (paper 2).

Although coarse-grained, the postglacial climatic trajectory and associated biogeographical presentation in Rankama (2003:41-42) contains several rallying-points with my own research. While Rankama (2003:45) suggested that increasing sea surface temperatures of the post-glacial period might have resulted in declining coastal resources and a potential population decline on the Norwegian coast, Grydeland (2005:39) sees no coincidental trends when conducting his multi-proxy assessment – a disagreement likely testifying to insufficiently resolved and consistent proxy data at the time. Beyond that, the many papers by Tallavaara et al. exploring the correspondence between long-term human population- and environmental dynamics in Finland (Tallavaara et al. 2010; Tallavaara and Seppä 2012; Tallavaara et al. 2015; Tallavaara 2015; Tallavaara and Pesonen 2018) have arguably been instrumental in establishing human ecodynamics and demographic modelling within Fennoscandian archaeology at large, while fronting a most explicit “climate forcing” perspective. The approach taken here is greatly indebted to these works.

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seal there, where the Norwegians settled at Østerbygda perished a century later. These are the paradoxical differences that the same place can offer, for their existence, to two populations of different customs and cultures. What is death for the one is a chance of life for the other. For the Arctic hunter, the cold can be synonymous with life, and warmth with death. Now imagine that the Finnmarkien peoples have arrived in an Arctic Finnmark more-or-less similar to today's Greenland, with the pack ice surrounding the coast. Then imagine them depending above all, for their existence, on an animal, the Seal, and on the purely arctic fauna that accompanies the seal. They adapted their life and their hunting technique to these new conditions. But this life, with its valued customs, was only possible as long as the pack ice bordered the coast, that is as long as the climate was sufficiently cold. A period of milder temperature, with an ice-free coast, would on the contrary be a catastrophe for them, because they could no longer find anything to subsist upon, or, putting things for the best, because there was a serious difficulty to overcome. One could deal with this by adapting hunting and lifeways to the new conditions - and this adaptation could easily have attracted peoples from the West and the South, that is, from areas where it was easier to live with the new conditions - or by following the pack ice, the seals and the purely arctic fauna. When we consider what extreme repugnance primitives have to changing their life, this last assumption is perhaps not the least true. And for future researchers, the question will undoubtedly be whether the continuation of the Finnmarkien civilization should not be sought towards the east, on the Kola Peninsula, on the shores of the White Sea, and perhaps even further east, just as we think that it is in these regions that we are most likely to find the stages which immediately preceded the migration of peoples towards the North” (Bøe and Nummedal 1936:255) [translation by Bryan Hood, from French].

The establishment of middle-range causal mechanisms between the micro and macro scale of socioecological systems has not been a favored topic locally. It has rather grown out of the current research interest in long-term H.E. and climate forcing. Even within this field, middle-range mechanisms have not been the priority, so much as long-term change at the macro scale. While there have been the occasional encounter with middle range theory of the Binfordian, ethnoarchaeological sort in the local research history (e.g. Bjerck 1989:2), here I am concerned with the analytical "middle range" of the Mertonian, sociological sort [Section 3.4]. The current thesis therefore aims at advancing the study of explicitly multi-scalar human ecodynamics and how such are brought about through aggregation and feedback between interlinked scales – using the archaeological record of coastal Arctic Norway as a case study. An obvious linking mechanism between macro- and micro-scaled components of H.E. systems, is that of technology. Technology acts as the mediating factor in human coping- and adaptive strategies, as the extrasomatic means of adaption. It is therefore crucial to determine the role of technology in mitigating external change and instigating adaptation when attempting to piece together the micro/macro scales of integrated socioecological systems.

The study of technological responses to environmental and ecological change in northern Fennoscandia is an emerging field, partly related to the Finnish school of H.E., - Manninen et al. (2018) being a most explicit example of the sort - but as much growing out of the eastern arrival hypothesis and the spread of pressure blade technology. Either way, Mesolithic cryptocrystalline technologies have been the primary target.

In approaching the tripartite relation between environment, human demography and technology, this thesis is also concerned with how technologies may have been used as part of the coping repertoire of the past when facing environmental risk. Paper 4 targets this issue directly in investigating the role of adaptive strategies, mediated through technology, in shaping long-term population trajectories, while also developing middle-range mechanisms better explaining feedback-loops between demographic parameters and technological capabilities of a population (Jørgensen 2020:2). This was attempted through tracking the evolution of maritime slate tool technologies in direct response to H.E. push and pull-factors - studied in detail in paper 4 and discussed in [Section 4.7]. It was suggested that "slate industries hold great promise as case studies for identifying and dissecting the general processes that produce interlinking between demographic and ecological parameters, and the technological capabilities of human populations" (Jørgensen 2020:43). This has been important, both in extending the study of technological responses beyond the Mesolithic (into the LSA and EMA), but also in targeting a very different component of the northern Fennoscandian lithic toolbox (slate technologies) that has been largely neglected. This has further been motivated by the unfortunate lack of synthetic lithic studies in Arctic Norway, with most knowledge existing as grey literature in e.g. excavation reports.

This is in contrast with the long track-record of lithic studies within Swedish archaeology, with Kjell Knutsson as a leading scholar, and more recently scholars in Finland (e.g. Tuija Rankama and Mikael Manninen) and southern Norway (e.g. Hege Damlien, Lotte Eigeland and Inger Marie Berg Hansen) that have put the chaîne opératoire approach firmly on the agenda. Studies investigating the Arctic Norwegian lithic record within a dynamic technological framework, consistent with that of adjacent areas, however, are still lacking. This constitutes an obvious avenue for future research. Instead, there has been a marked interest in the geological availability and provenance of lithic resources, most notably concerning chert (Hood 1992), while ongoing research investigates slate raw material outcrops across the Caledonian range in the Norwegian-Swedish border (Hallgren 2012, in press).

In sum, this review of prior research demonstrates some of the dominant research trends of demographic relevance within the study area. Yet it also reveals considerable blank spots concerning direct and systematic investigations of integrated, socio-ecological change. Although prior research did occasionally address themes related to my study - important groundwork I acknowledge and appreciate - it is safe to say that human ecodynamic approaches have not been a prominent research agenda in Arctic Norway and thus merit dedicated study. What is equally striking, is that the majority of human ecological/human ecodynamic research in northern Fennoscandia has targeted Early Stone Age human/environmental dynamics – preoccupied with colonization processes and their related ecological conditions (Bjerck et al. 2016; Breivik 2014; Manninen et al. 2018; Persson et al. 2018) Blankholm [ed.] et al.; Manninen et al. 2018). This provides additional justification for the particular interest in Late Stone Age dynamics of the current thesis. The prior debate of terminal LSA demography at site and household scales provides important groundwork yet is in need of explicit linking with other components of socioecological systems, preferably within a human ecodynamic framework.

In an attempt at not only synthesizing and providing an up-to-date account of previous research, but also to make a more substantial and novel contribution to research-historical investigation, a more interesting thing to discuss in this context is what has <u>not</u> previously been done. What has been lacking are population level demographic studies and the tracking of long-term trends. Then the question is “why”.

2.2 The static population assumption: Epistemic challenges

In identifying likely reasons why population level demography and adaptationist issues have seldom been addressed in Arctic Norwegian archaeology, it may initially seem like a natural consequence of attention being directed at a different set of problems, particularly those of social structure, symbolic meaning and ethnic relations. Case in point, the work by Olsen (1994) has been highly influential in this regard, acting as the culmination of important research trends in Arctic Norwegian Stone Age archaeology. Although acknowledging the logistics of limited resources, I suspect another fundamental reason has been influential in driving the lack of palaeodemographic and H.E. research in the area: an assumption of demographic stasis, henceforth “the static population assumption”. If one implicitly/unintentionally assumes minimal demographic change and fluctuation through time, this would undermine interest in demographic and H.E. issues that per definition are the study of change. In a stronger case of intentionally discounting demographic change, assuming long-term static equilibrium to be the population historical norm, then demography would be regarded as an irrelevant topic, effectively making H.E. research and its focus on change in socioecological systems redundant. If it is true that there has been a static population-assumption in play, then this raises the fundamental question of how and why **change** occurs in the first place. Consequently, this has major implications for how we are to study, let alone explain, change in past cultural systems. In the following I discuss how assumptions of minimal demographic change through time may have set precedence not only in the local archaeological practice, forming the knowledge basis on which this thesis had to build, but also in the form of deep-rooted *epistemological* premises within the archaeological discipline at large.

2.2.1 Stasis and data interpolation

The intention of H.E. research may seem utterly banal in emphasizing dynamics (change) as a phenomenon worthy of study, yet our basic assumptions concerning how and why change occurs have direct consequences for the entire archaeological enterprise to a degree that can hardly be overestimated. Although explanations of change have varied throughout the history of archaeology, ideas of stasis and stability have a particularly long track record. This has taken multiple and diverging forms. For instance, long-term human evolutionary perspectives have tended to emphasize stable states and equilibrium with the environment and was early on expressed through determinist anthropogeography and romantic primitivist views (e.g. Montesquieu 1989[1748]:231–245). However, it has been far more common to approach change (or mostly the lack thereof) as an **internal** affair of the cultural system in question. That is, patterns of cultural inheritance seen as continuous with a tradition until they are interrupted by diffusion or migration processes, which was engrained in traditional culture historical archaeology. From the onset, culture-historical archaeology was fundamentally invested in internal dynamics:

> "*The most important assumption was that the spatial or chronological entities represented human group traditions. It followed from this that major changes could occur only through the replacement of one tradition, and therefore one people, by another, at least in those cases where material culture production was domestic [i.e. hunter-gatherers] rather than in the hands of specialists*" (Shennan 2000:811).

The very act of periodization (an act partly responsible for establishing the archaeological discipline in the 19th century) gives the impression of static historical development through time, with changes mainly occurring at the transition between chronological units. Although promising to disentangle chronology as a constituent factor in upholding static views, Shennan does not really get around to explaining exactly how, beyond pointing to the glossing over of dynamic processes by broadly inclusive chronological periods (Shennan 2000:812,819). Yet the problem at stake in this case is a sub-variety of the potential pitfalls of **interpolating** which the insertion of an intermediate value into a series by estimating or calculating it from surrounding known values. When applied to timeseries, interpolation between data points can be problematic when the representativity of an underlying pattern or sample is unknown. Interpolating between fragmented data points is a methodological practice used to create consistency of values within a time series believed to be continuous. However, this runs the risk of glossing over significantly varied and fluctuating trends in a timeseries. When applied to the inference of population trends from archaeological proxy data, interpolation is inevitable given the commonality of poorly resolved archaeological data. Yet interpolation may easily give the impression of long-term statics and equilibrium in population historical reconstructions if taken at face value.

Intuitively, weaknesses of interpolation may appear like an issue solely concerning data resolution: if a dataset is well enough resolved, the need for interpolation disappears. However, it is a fundamental **epistemological** problem for any analysis of timeseries data, on which all historical sciences are particularly reliant, and by implication, particularly susceptible to err. Although methodological improvements and increased data resolution help abate/reduce the space of uncertainty they are restricted to what is self-induced through current practices and technical abilities (Jørgensen 2015:83). No level of empirical resolution can solve the issue completely, given the inherent (*a priori*) uncertainty of archaeological data. There will always be substantial empirical uncertainty that can only be overcome through analytical inferences into propositions and knowledge claims.

The problem is that of the **underdetermination** of theory by data, whereby there are insufficient grounds on which to discriminate between competing hypotheses or explanatory accounts (Stanford 2013). Yet the epistemic issue is not restricted to that of data resolution alone but, as forcefully demonstrated by Perreault (2019:23–39), equally pertains to other qualities of archaeological datasets, such as sampling interval, dimensionality and scope. Additionally, there is the concern of whether the archaeological record can be considered meaningfully "representative" of what we want to know in the first place. Given the agency and adaptive flexibility of human actors shaping and producing the archaeological record, some have been critical of the prospect of obtaining meaningful/truly representative distributions (e.g. Gero 2007; however, see recent review of sampling strategies and its history in (Banning 2020)). While the distribution of material cultural remains inform us of human behavior in ways that differ from directly observable behavior (Wobst 1983:37) – which arguably, is the very strength of archaeology – it also highlights the epistemic gap between material correlates and many aspects of human behavior, societies and adaptive features of interest to us. Such has to be inferred, although at various levels of uncertainty (cf. Hawkes 1954). Add to that all the local, national and global inconsistencies in data collection and reporting, and the picture may seem rather bleak. Regardless of stance in this matter, it points to the epistemic problem when wanting to extract information on long-term historical trends and short-term events reconstructed from sparse, incomplete and non-normally distributed data. It is therefore a predictable outcome that the stipulation of trends between few data points may give the impression of stasis or gradual change, regardless of the potential high-frequency/high-amplitude fluctuations characterizing the actual, underlying pattern.

The problem is manifest in a more general sense in archaeology, as constructing chronologies based on inherently fragmented and course-grained archaeological data runs the risk of imposing artificial stasis *within* periods and equally artificial boundaries *between* periods – none of which may correspond particularly well with actual demographic events in the past. Related criticisms have been voiced concerning the potential bias towards stasis in archaeological chronologies following interpolation and visualization of temporal trends (e.g. Madsen 1978; Ramenofsky 1998). Yet such criticisms are surprisingly infrequent considering how pervasive these issues are and how they should merit contextualization and discussion within every regional archaeological tradition. In this case, it is pertinent that very little thought has been afforded how such interpolation impacts the way we conceptualize population dynamics specifically, and cultural change in general. The infrequency of such thinking being put to paper, I claim, has made stasis and stability into a default archaeological understanding of palaeodemography – figuring in recent studies, yet more pervasive in pre-modelling approaches to long-term cultural change. The most direct attempt at raising awareness of the issue is that of Shennan (2000:812), stating that if we are to explain change, "it is essential to take into account the role of past population dynamics, which is crucial to many if not most processes of culture change. Failure to appreciate this is at least partly a result of the inadequacies of archaeological chronologies". This is a foundational issue that should be explored at greater depth in future research.

Stating that past interpretations based on interpolation between datapoints spread wide across time and space potentially conflate ***demographic*** fluctuations, however, does not necessarily entail or directly relate to issues concerning ***cultural*** continuity or discontinuity. Population size, cultural traits, technological complexity and the cultural continuity necessary for cumulative knowledge transmission to take place are intuitively related, yet in ways that eludes linear and mono-causal reasoning. The non-linear and complex properties of human behavior and adaptability has, for that very reason, generated an extensive scholarly production across the human sciences (e.g. Moran 2009). Interesting and important as such topics are, they are beyond the scope of this thesis. Although, the fact remains that the local archaeological practice within the study area is not unique in its more or less implicit reliance on static assumptions of demographic trajectories. Rather, it is in line with deep-rooted scholarly traditions in Scandinavia – with foundations in early culture history research – and, more recently, part of a western European, post-processual tradition. The former emphasizing gradual change within traditions, the latter, change as actions and reactions to the internal social dynamics of cultures. My express contribution in this thesis is therefore framed as an attempt at investigating if, and what character, potential population dynamics might display in relation to a wider socioecological setting.

2.2.2 Stasis and assumptions of internal causality

Beyond the conceptual realm and its contribution to the perception of stasis and stability, more recent intellectual trends have also been crucial in producing static conceptions of hunter-gatherer demography. Today it is common knowledge that foraging has been the dominant adaptive strategy throughout human evolutionary history. Yet this was not believed to be the case until quite recently. The natural state of man and society has been a favored topic since the Enlightenment. Consequently, hunter-gatherers have been the object of a plethora of conceptions across the spectrum of romanticism to "primitive" narratives. Intriguingly, hunter-gatherers were in early scholarly thought believed to lead an intrinsically unstable way of life (Barnard 2014:45). The concept of stability developed much later and mostly in the 20th century, and is to some degree attributable to the "generalized foraging model" of Lee and Devore (1968), and the "original affluent society" of Sahlins (1968), which equally assume an equilibrium model of HGs: 1) Ecologically, in that subsistence is unproblematic. 2) Demographically, as consisting of small groups. 3) Technologically, as low-octane/low complexity adaptations whereby the "technical means [are] unchanging but on the whole adequate" (Sahlins 1968:85).

The rather recent construct of "hunter-gatherers" as a conceptual category is partly responsible for the static connotations, given its originally evolutionary underpinnings (Barnard 2014:49). Later, neo-evolutionary research emphasized how prehistoric HG´s can evolve into complex organizational forms, and crucially, that this is often associated with elevated population numbers and densities (e.g. Price and Brown 1988). This also instigated an interest in understanding the drivers of such adaptive variability and convergent trends among distinct human groups. Following the New Archaeology agenda (processualism), the root cause of such trends was sought in external (e.g. environmental) push and pull factors. Causation itself never was a major topic until the New Archaeology made it a key concept. Prior to the height of processualism, cultural changes were accounted for as a series of *historical events* occurring consecutively, often without explicitly stating explanatory mechanisms responsible for the invoked change.[4] This is demonstrably true also for the explicitly post-processual archaeology of the 1980s-2000s. Therefore, processualism appears to have been more concerned with dynamics and change among HG populations than post-processual thinking. The latter emphasized internal and action-based drivers of change in reacting to the apparent environmentalism of the New Archaeology. Nowhere has this been more clearly expressed than in Ian Hodder´s *Reading the Past*, when claiming that:

[4] Although an awareness of and interest in ascribing causal responsibility to particular variables in explaining change was clearly visible throughout culture historical research, the reliance on macro-level properties such as migration/diffusion, is not here considered as explanatory mechanisms given the lack of explanatory reductionism and scalability of such accounts.

"*cultural relationships are not caused by anything else outside themselves. They just are*" (Hodder 1986:4)

What the approaches of culture history and post-processualism have in common, is treating change and human action from an "**internal view**" – that is, explaining cultural change in terms of its internal dynamics, specifically by pointing to micro-level "**proximate causes**". Proximate causes are those that immediately precede the change one wants to explain, and is primarily related to micro-scaled events.[5] This tradition grew out of the culture-historical interest in particulars – that is, particularism as the guiding principle of study and for "tracking" (rather than "explaining") change. This is a particular expression of a fundamental static assumption in archaeology driving cultural continuity. Cultural continuity, as inferred from long-term similarity (stasis) in material culture, was often taken to imply a strong degree of social/political reproducibility. The idea was that the goal of culture is to reproduce itself - that is, to maintain conformity to cultural norms – famously criticized by Binford (1965) - which leads to the static view inherent to culture-history in which continuity of traditions are only broken by migration/diffusion.

When it comes to post-processualism, the gravity of Hodder´s claim is rather perplexing in its extreme discounting of ultimate causes. It is difficult to understate the degree to which this view highlights internal and proximate causes of change, while simultaneously rejecting the relevance of external factors to cultural phenomena. I suspect the implications of this claim were not fully comprehended by its proponents. However, it came to be an important inspiration for some practitioners in Arctic Norwegian archaeology. A popular and related view of the 1980´s, which became highly influential after its introduction to northern Norway following Olsen (1984), is that of structural Marxism and its focus on social reproduction. According to structural Marxism, change comes (mostly) from internal "contradictions" that accumulate over time as people/groups strive for power. Yet these power struggles play out *independently* of external factors. Or, as in the classic case of Bender (1978), stressing that the efficacy of external environmental or demographic causes of change in cultural systems is mainly a byproduct of social structure. In the more extreme cases, this turns into a reiteration of the claim that "culture just is" – paraphrasing Hodder (1986:4). Cultural change, thus perceived, is best conceptualized as a closed system. No external perturbation may have an influence, both because external variables were thought to be secondary but also because externalities (supposedly always) are mediated through primary, internal variables:

"*Even if human beings are indeed animals and subject to processes of natural selection in an equivalent manner to badgers, hedgehogs or guinea-fowl, this by no means implies that any adequate explanation or understanding of social totalities, institutions or material culture patterning can be achieved by reference to either natural selection or adaptation. Most social and material practices have no demonstrable physical survival value for human populations whatsoever*" (Shanks and Tilley 1987:154–5).

The implication is that the innate behavior of cultures is **teleological** in seeking stasis and internal equilibrium through reproduction of normative culture. This is surprising when considering that, in fact, it is comparable to the assumptions of early systems theory (prior to the recognition of tipping points and dynamic equilibria), which was a major target of post-processual criticism. However, this teleology is incapable of accounting for why changes occur in the first place. Invoking societal

[5] Originally introduced to biology by (Mayr 1961) to analytically separate causal agents in biological evolution - that is "proximate causes concern processes occurring during the life of an organism while ultimate causes refer to those processes (particularly natural selection) that shaped its genome" (Francis 1990:401). Although its continued usefulness to biology is being questioned (Laland et al. 2011, 2013), I believe it legitimate in the social sciences as a specific type of the distinction between micro/macro-scaled causes.

dialectics between power groups, structures or individuals as the driver of change easily results in circularity. The circular logic of internal causation is well exemplified in the local archaeology of the Gressbakken phase (4200-3500 cal BP; see paper 2), in which the argument for increased inequality (internal contradictions) was based solely on assumed sedentism and communal houses (Myrvoll 1992:151,172; Olsen 1994:92; Schanche 1994:181). Yet, when no reason is given for the initial sedentism with ensuing inequality that produce contradictions, the explanation for the collapse of the system becomes fully self-referencing when citing an antecedent effect as the causal driver. That takes us no further than where we started off. This account is clearly inadequate in not providing a mechanism driving the alleged internal change and relating the change to ultimate/distal causes - in this case - the neglect of external drivers. This also exemplifies the historical contingency basic to much of post-processual causal thinking, in which change is treated as happenchance.

To the extent that human demographic/environmental links have been explicitly stated in the local research tradition, they have also been the subject of static assumptions (e.g. Odner 1964:122). Regardless, it became more common to emphasize the internal over external factors in the following decades, as exemplified by Schanche (1995:185) when claiming that:

> "*The [Gressbakken phase] record displays regional and chronological variation that may partly be due to variations in natural conditions and resource availability, yet must first and foremostly be seen as the result of local traditions and the organizational composition and territorial affiliation of particular groups*" [my translation].

Suggesting that my predecessors adhered to a static population assumption may not be overly charitable. Although direct evidence of static assumptions may not be commonplace, reviewing the local literature and archaeological practice suggests that static assumptions constituted important discourse premises and tacit knowledge. The implicit idea has been that the local population displayed remarkable stability ever since the land was colonized after deglaciation, approx. 12.000 years ago, and until today – something that has been criticized both by insiders and outsiders to the community (Hagen 2011:24; Rankama 2003:43). Previous research has emphasized intrinsic factors as the main driver of change in Arctic Norway, with minimal interest in external factors. Consequently, it has been suggested that the dominant view in previous research downplayed demographic fluctuations and environmental impacts on the Stone Age population in favor of stasis and continuity narratives (Hagen 2011:23,86). The static population assumption and the related internal view are best exemplified by the particular use of ethnographic analogies in the area.

2.2.3 Stasis and analogical extrapolation from ethnography

Following the discussion of epistemic challenges of interpolation and the often resultant stasis/stability [Section 2.2], the role of ethnographic analogical reasoning needs to be considered as it is one of the key resources used to bridge the gap between the past and the present. Yet while both interpolation-based and analogy-based inferences may be considered subspecies of extrapolation (the terminology is somewhat unclear), it should be noted that analogical reasoning entail an attribute matching between comparative cases with the aim of assessing degree of similarity which is not identical to interpolating intermediate values in timeseries for instance (see Bartha 2019). Although the inference process is different, both analogical and interpolation inferences imply the analytical and epistemic **extension** of attributes from known objects onto that of unknown objects.

For an empirical and historical science like archaeology, epistemic extension contains what is intrinsically a gordian knot: we want to study phenomenon that are not directly observable (being in the past), and whose material remnants may be either unreliable, irrelevant or reflect practices unfamiliar to us. Transcending this problem is a constant issue in any archaeological inference process yet is arguably more pressing in the study of lifeways very different from our own – such as hunter-gatherers societies of the deep past – and even worse, when studying intangible phenomena such as "palaeodemography".

The most common way to deal with this problem has been to employ ethnographic data of groups assumed to share relevant traits to that of archaeological populations. Yet ethnographic analogies are subject to problems related to that of interpolation in representing potentially highly particular features of a specific group, and thus not suitable for deep-time extrapolation in serving as a template for properties of past people. More critical here however, is the fact that the analogical reasoning used to reconstruct past hunter-gatherer societies from ethnographic data often imposes static assumptions of deep-time population trajectories. The demographic patterns of ethnographically recorded hunter-gatherers, including Sami people, have been demonstrated to be significantly different from those derived from current palaeodemographic models (Tallavaara and Jørgensen in press). Employing ethnographic data for palaeodemographic or archaeological purposes more generally, without considering the suitability of scale and data resolution, may lead to fallacious inferences. As the study of palaeodemography has strong roots in the use of ethnographic data for the reconstruction of past demographic states of affairs (e.g. Weiss 1973) - with associated assumptions and established frames of reference – I deem it necessary to clarify how this thesis relates to this tradition.

From the very onset of Arctic Norwegian archaeology, historically and ethnographically documented Sami communities constituted the archetype for reconstructing Stone Age societies. This is not surprising, as hunter-gatherer research in the area could benefit from what is globally a rare opportunity of having access to living communities of contemporary hunter-gatherers on which to make ethnoarchaeological or ethnographic analogues with the past. This has provided a wealth of otherwise hard-to-get insight into the past, by way of analogical reasoning.

However, analogical reasoning that extrapolates past states from historical/contemporary conditions faces a host of associated problems and pitfalls related to the projection of recent adaptive and social properties into the deep past, sometimes without considering the major changes and historical contingencies that have shaped the ethnographic record (Salmon 1982:57–82; Wobst 1978; Wylie 1985). A case in point is the 1980s "Kalahari debate" concerning the degree of relevant continuity between past archaeological and present ethnographic states among the San, which questioned Richard Lee's highly influential "generalized foraging model" for hunter-gatherers (Lee 1979; Lee and Guenther 1991; Wilmsen 1989; Sadr 1997). Although the archaeological support for various claims in the Kalahari debate still is a matter of contention, there is no question that the majority of ethnographically documented HGs have been significantly impacted by sedentary and food-producing people as well as commercial economies, power relations and colonialism. This makes a significant difference compared to the conditions of the Palaeolithic when all relied on foraging for subsistence. Thus the relevance of much ethnographic data for analogical reasoning in archaeology is a matter of contention: it may imply assumptions of long-term demographic and cultural stasis, and thereby downplay change as a fundamental research topic in archaeology, as well as being complacent about explaining the past. Static assumptions sometimes rely on dubious ethics, implicitly the "non-changing nature of primitive people", although in other contexts the positive emphasis on resilience among non-industrialized people can likewise constitute a static assumption.

An important contributor to the static population assumption in this regard is the romanticism portraying hunter-gatherers as harmonious and perfectly adapted to the environment, in constant equilibrium and enjoying "Garden of Eden"-like conditions in "the original affluent society" (Sahlins 1972:1–37). Unfounded assumptions of equilibrium or harmony simply maintain statics as the dominant understanding of the deep past. In terms of palaeodemography, the implication of such romanticized long-term stability is the discounting of significant and frequent populations fluctuations as carrying any real explanatory clout.

In north Norwegian archaeology there are a number of examples of how ethnographic analogies can sustain the static assumption. Particular focus has been directed at the social and organizational structure of the *siida* (band-like group in Sami society, often linked by heredity). The network of siidas has been reconstructed historically for most of northern Fennoscandia and the Kola peninsula (Niemi 1994; Vorren 1980, 1989). The Skolt Sami of the Norwegian/Russian border area (Tanner 1929; see also; Solem 1933; Vorren and Manker 1981) has long been the baseline for archaeological interpretation in the area (as reviewed in Berg 2001), due to the assumption that they displayed unprecedented cultural continuity (statics) into the 20th century – to the extent that Tanner (1929) originally described them as having an unchanging nature. As late as in 1989, Knut Odner (1989:76) stated that the Skolts were prime candidates for analogical reasoning "because the original [Skolt] culture was conserved until an adequate depiction of the organization could be made" (see also Olsen 1987). However, recent research has firmly refuted this model, demonstrating that Skolt societies were impacted by involvement in the commercial economy and by Russian administrative practices (Berg 2001:121; Hansen and Olsen 2004:178–185, 2013:168–174; see also Hood 2015).

Gjessing (1955:90) made explicit the assumption of shared social and demographic structure between Stone Age groups and historic Sami populations, and used data from Sami ethnography to adjust population expectations for the archaeological past (Gjessing 1955:88). Similar analogues have later been echoed by multiple researchers in the area, with social structure and associated territories of the Sami siida providing important analogical parallels to the interpretation of the archaeological record – particularly concerning the Gressbakken phase (Helskog 1984; Odner 1993:76; Olsen 1984:99; Sandmo et al. 1994:120; Schanche 1988:201, 1994:169, 1995; Simonsen 1965, 1972; cf. Hansen 2009:220; cf. Havas 1999:107,119; Skandfer 2003:372). A most explicit example of the static assumption is presented by Schanche when inferring Stone Age equivalents of the Sami siida structure by way of direct analogy:

> "*there exists a certain correspondence between groups of Gressbakken houses and the siida territories: this is true of the Varanger and Neiden siidas. It is tempting to see this coincidence/correspondence as expressing continuity from the Stone Age hunter-gatherer societies to the historically documented Sami settlement in the area. … I believe that moving into the modern times saw the final remnants of a territorial division of the Varanger area dating back to the Late Stone Age*" (Schanche 1994:171)[my translation].

This was also done for the Early Stone Age when claiming that "The social organization of the Early Stone Age had certain corresponding features to that of the traditional Sami form of organization – the Sii´da» (Schanche 1988:201)[my translation]. Similar statements permeate the literature, suggesting more or less identical population size, adaptations and social structure between Stone Age groups (often of indefinite time-depth) and historic Sami populations. For example, Sandmo et al. (1994:42) claimed that: "The Tromsø area had a permanent population already 10.000 years ago. The amount of people could have been around 50. It appears that this population size has been somewhat stable throughout the entire Early Stone Age")[my translation]. Similarly, Andreassen assumes long-term demographic stasis when claiming that "every little fjord and inlet on Sørøya Island had a permanent settlement **throughout the Stone Age**", suggesting settlement sizes ranging from 2 to 6 contemporaneous houses, that is, up to 25 people (Andreassen 1985:250)[my translation, emphasis added]. She discusses demography at various scales, including the household, site and village, but without considering the wider implications for the population level. In fact, she at one point suggests that the site level population size likely stayed constant throughout time (Andreassen 1985:247). Finally, Odner (1964) also asserted static ecological and analogues demographic conditions throughout the post-glacial period, claiming that: "As there are such great likeness in the ecological conditions, one may tentatively use current settlement around the Varanger Fjord today as the baseline for reconstructing the settlement pattern and economy of the Komsa culture" (Odner 1964:122)[my translation]. This statement exemplifies the tendency to assert long-term statics. It also seems an understandable product of its time, considering that the data was unfit for identifying anything but very gradual change and the lack of analytical frameworks for recognizing rapid changes.

Note that the tendency of inferring analogical relations between the social and adaptive features of Sami and prehistoric groups in the area appears to have dropped markedly since the 1990s – although, see Grydeland (2005:45). It is not clear if this is due to changing perceptions of this analogical relation or just due to the lack of interest in the associated topics ever since. However, the potential pitfalls of doing so have been reviewed on multiple occasions (Berg 2001:76; Havas 1999; Skandfer 1995, 2003:356; cf. Rankama 2003:44).

These examples point to how local ethnographic/historical cases can contribute to sustaining static population assumptions within Stone Age archaeology relying on analogical reasoning. Although some of these issues might be addressed by turning to the global ethnographic dataset, there are significant caveats concerning the underrepresentation of coastal and marine adapted hunter-gatherers that undermines its usefulness to the coastal focus of the current thesis. I have rather come to rely on circumpolar ethnography in the broader sense, after it had inductively proved its usefulness in providing predictions of human/environment interactions corresponding to my own results. This is most clear in the discussion of convergent evolution of maritime adaptive features across the Circumpolar region in paper 4 and discussed below [Section 2.3]. This workflow may not have been explicitly stated in the papers, yet I take this to be an important analytical heuristic that is distinct from the inverse process of deducing local archaeology from ethnography – common in previous research.

This extensive evaluation of the static population assumption sets the stage for my own project and highlights what is an apparent need to rethink and test established assumptions. Then what is the alternative to the internal view?

2.3 The dynamic population conception: The external view (ultimate causation)

Whereas the static population assumption was, precisely, an assumption, our understanding of past populations is becoming increasingly dynamic – underwritten by empirical results. Multi-millennial statics is the exception rather than the rule.

Contrary to assumptions that have been dominant in the international community, population stasis has been demonstrated an impossibility over evolutionary time scales (Gurven and Davison 2019). The implication is that human populations in the past would have experienced dramatic crashes and, most likely, regional extinctions on a regular basis (Riede et al. 2018). Even on relatively short time scales, such as that of centuries, this pattern has now been confirmed across the globe by palaeodemographic studies that reconstruct how past populations developed through prehistoric time. The aggregate results across continents, covering the late Pleistocene and the entire Holocene record, is that of highly dynamic population histories with repeated boom-and-bust cycles. Long-term studies of human evolution have tended to emphasize stable states and equilibrium with the environment, however, this has been fundamentally challenged by increasing chronological resolution and modelling capabilities – stressing the importance of so-called "socioeconomic disequilibrium" (Riede et al. 2018). The highly dynamic results are much more in line with the ethnographically documented patterns of high-frequency demographic fluctuations, and therefore more empirically defensible. The apparent stasis and stability of the archaeological record should thus rather be attributed to the low-amplitude of fluctuations within already small, prehistoric hunter-gatherer populations not accurately showing up in the course-grained material record of archaeology (Tallavaara and Jørgensen in press).

Now that dynamism and abrupt change is established as a common feature of human history, explaining "change" takes on a different role compared to the previous accounting for long-term, gradual change. The focus of adaptationist thinking drastically shifted from culture/folk as historical entities, to biological populations as adaptive entities with processualism. As stated by Shennan (2000:811): "The key to understanding culture change was to see the artefacts produced by human communities in terms of their role as means of adaptation rather than as reflections of population replacement or cultural influence". Thus, change is not simply something that "happens", it is the active response to stimulus (in various forms, be it internal or external to the cultural system). This leads us to the "**external view**" – in which cultural change is explained in terms of external dynamics, specifically by pointing to macro-level "**ultimate causes**". The external view and human ecodynamics are fully compatible in that both view cultural change as the sum total of causal influences on complex socioecological systems. The interest in ultimate (at least distal), over proximate causes, has to do with the ambition of explaining rather than merely describing change. The real reason(s) for change in complex systems is rarely (if ever) mono-causal, but instead a set of nested influences that in aggregate produce a result. This fact was clearly communicated in Binford´s suggestions for archaeological research designs:

> "*changes in cultural systems must be investigated with regard to the adaptive or coping situations which are presented to human populations. If we are profitably to study process, we must be able to isolate cultural systems and study them in their adaptive milieu conceived in terms of physical, biological, and social dimensions*" (Binford 1964:426).

Although internal factors undoubtedly are important in making history unfold, their causal influences are mainly restricted to the micro-scale end of the analytic spectrum. At the **micro scale** in human/cultural systems, the actions and events are most appropriately described by reference to human agency. Desires, beliefs and opportunities are the fundamental constituents of micro-level human behavior (also known as the DBO-model) (Hedström 2005:38), and are fundamental to methodological individualism in explaining human behavior. Yet, these constituents do not emerge in a Platonic realm of pure ideas or "brains in a vat" (as apparently has been the fashionable assumption among post-modern social theorists) – ideas that have also become influential in archaeology through late adoption. <u>Rather, the very desires, beliefs and opportunities of social beings are the result of evolutionary selection pressures, attuned to environmental conditions and mediated through the</u>

behavioral organism that is the human psychosomatic entity. This is why reductionism is a necessary basis for evolutionary ecology when applied to archaeology (Winterhalder and Smith 1992:15). What was forgotten by post-processualism in its insistence on internal drivers of change, was that members of the same species constitute competitors whose mutual interference make up a considerable part of each other's environment. Culture is part of the adaptive niche that humans must cope with in order to propagate.

At the **macro scale**, explanations focus on the aggregated outcome of many events that also span considerable time. This is done with reference to general principles derived from evolutionary and ecological theory. The appropriate explanation depends on the level of analysis, but not so alone. It also depends on the resolution of available data. In archaeology, data resolution rarely permits explanation of micro-scaled phenomena. Crucially though, a central premise of integrated, multiscale analysis in archaeology (be it H.E. or any other adaptationist frameworks) is that human agency is an evolutionary product, fine-tuned through selective pressures. Framed as a scalar argument, this implies that macro-scale environmental conditions feed back into selecting for micro-scale human behavior (seemingly compliant with principles of optimization/satisficing or not). Logically, explanations of seemingly micro-scaled human phenomena within a framework prioritizing internal (social) variables will be incomplete without explicit coupling of how motivations and strategies are embedded within externalities. Accordingly, the reductionist explanatory account in analytical social science is that macro-scaled events and properties can only influence other macro-scaled events/properties by way of inducing change in underlying, micro-level states – as illustrated in (Fig.5). This is to a large extent what middle-range theory is about - discussed in detail [Section 3.4].

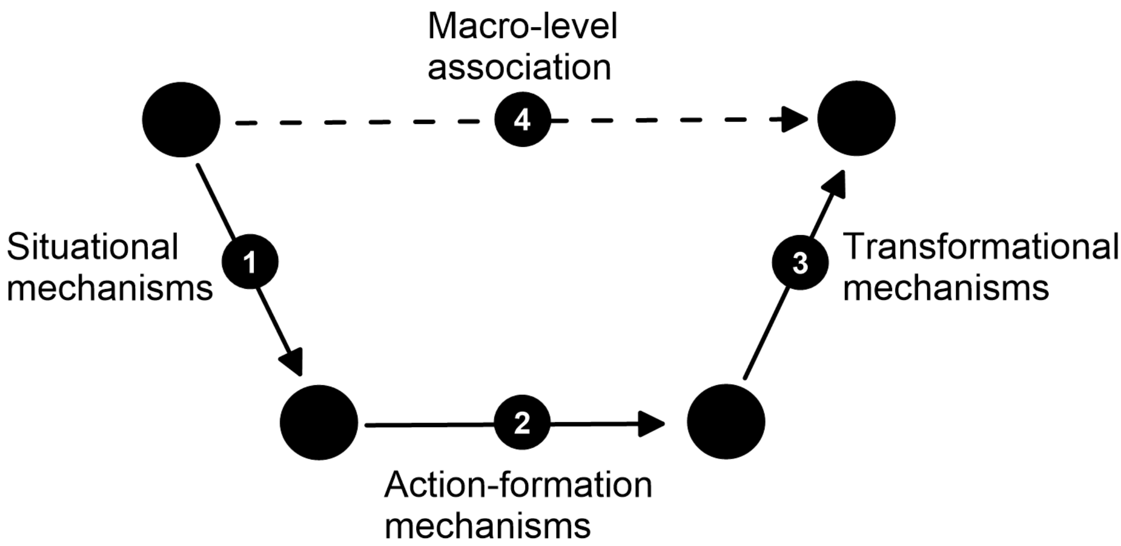

Figure 4 Illustrating the reductionist explanatory account of how micro and macro scaled events/properties are causally linked - as originally formulated by (Coleman 1994). No direct causality in relation 4 (dotted line) can be invoked as an explanation of change between two macro-scaled events/properties. The causal efficacy of macro-scaled events/properties to induce change at the macro-level (relation 4) is only made possible by mediation through feedback-loops to underlying micro-scaled states (relation 1-2-3). Redrawn and modified from (Hedström and Ylikoski 2010:59).

It is important to acknowledge that complex socio-ecological systems do not lend themselves to simple reduction. Instead, they are fundamentally characterized by non-linear processes that occasionally defy classical parts-to-the-whole concepts. Being mindful of this caveat, I have tried to reduce the admittedly complex phenomena of integrated human ecodynamic systems to general evolutionary and ecological principles. This should be an acceptable analytical middle ground for linking micro and macro level phenomena, as the selection mechanisms of evolution act the same whether it be on genes (of any organism), material culture or human adaptive strategies. Descent with modification is the basic operator and outcome of all historical systems, be it physical (galaxies and molecules), biological (genes and behavior), psychological, linguistic and technological.

It is commonly recognized that the limited chronological resolution of the past inhibits our ability to reconstruct small-scale, short-duration events. However, the insistence on internal dynamics somehow overlooks this fact. When prioritizing political and social factors in explaining change in the archaeological record, one necessarily has to assume that the social and political units of archaeological analysis actually correspond to the scale and causal efficacy of their ethnographic counterparts. However, this has been disproven as even the largest ethnographic political units known barely correspond to the smallest units of archaeological analysis of pre-state societies (MacEachern, 1998; Wotzka 1997). Consequently, archaeology does not have epistemic access to internal dynamics in the consistent manner necessary to explain change at the scale of agency in past cultural systems.

The discussion of agency, intentionality etc. and the ability to "break free" of nature´s grasp, seldom moves beyond the context of state, or at least ranked, societies where the "agency" is easily identifiable as mediated through political structures. In terms of "Stone Age" applications however, such discussions are primarily associated with properly Neolithic/agricultural populations. We need only think of the mantra that "farming changes everything", and how sedentism and cultivation tentatively could be related to the social cohesion and political benefit of "big men" through feasting (Dietrich et al. 2012; Hayden et al. 2013). However, as has become apparent through various human ecodynamic research, the socio-technical ability of humans to transcend environmental parameters (carrying capacity) for extended periods is rather limited prior to state formation (Shennan 2000:812). In other words, macro-scale external drivers consistently produce cultural change that are not reducible to internal social properties. I touch upon this issue throughout my papers. Most specifically, paper 1 points to the commonly shared demographic trajectory across mid-Holocene Europe. The striking pattern of a pronounced mid-Holocene population peak across large spatial scales is more important than is often expressed, as the correlated human ecodynamic changes seem to be independent of adaptive strategies (foragers or farmers) (Jørgensen 2018:12). The issue of socio-technical capabilities to transcend environmental parameters is rather important to my thesis as it has major demographic implications. Paper 3 and 4 explore the role of subsistence technologies in bringing about a mid-Holocene population boom and bust-cycle in Arctic Norway. Despite what seems to be a partial contribution of maritime intensification to the population trajectories across northern Fennoscandia, the trend correspondence between demography and palaeoproductivity trends draws the causal efficacy of subsistence strategies into question (Jørgensen et al. 2020).

The impression of long-term stasis and stability of the archaeological record is increasingly turning out to be a fallacy. Working around the problem of population stasis is not just a matter of increasing the resolution of the empirical record. It is just as much a conceptual problem. What is at fault is the (implicit/explicit) *assumption* that until otherwise proven, continuity and stability should be posited. Considering that material culture is subject to descent with modification (through cultural/knowledge transmission), analogous to the genetic version in the biological realm, the material record of the past is inextricably linked with underlying demographic mechanisms. As stated by Shennan (2000:813) "what happens to the biological population has major effects on a great variety of cultural processes. Nevertheless, these effects would be largely irrelevant if past populations were relatively static and unchanging". Exclusively focusing on internal drivers of change make explanations highly susceptible to the static population assumption. Any change becomes the expression of social reconfiguration without further need to investigate the potential impact on e.g. demography, or the impact of demography on social reconfiguration – as might be expected from the duality of structure-thesis. It is rather taken as a given. Yet, when all other parameters are assumed to be stable, demography necessarily has to be stable as well.

The internal view lacks a concept of causality and lacks a mechanism for connecting internal and external factors. Such is provided by cultural transmission theory (Walsh et al. 2019; cf. Boyd and Richerson 1995; O'Brien et al. 2010), which is able to couple long-term adaptive consequences to human action through the concept of **descent with modification**: "the central importance of the inheritance process means that one of the key tasks is to distinguish similarities due to shared history and common descent (homologies) from those due to common or convergent adaptations (analogies)" (Shennan 2000:812). This is very important, as distinguishing between homologies and analogies is not possible within the internal paradigm. The culture-historical take on similarities was normative types or traits that reflected cultural norms, and the assumption was that cultural traits shared across space and time implied shared cultural origin (homology) – often framed in terms of ethnic groups or "kulturkreis". True analogies - convergent adaptations – do not make sense within this analytical frame. Case in point, Gjessing famously proposed that the striking adaptive similarities across the circumpolar region were due to a pan-Arctic migration (Gjessing 1953). Post-processual examples of this is more difficult to find, as comparative research designs were in low regard. In my own work, I have rather emphasized convergent evolution as similar responses to shared environmental conditions. This was done both in paper 3, when discussing Moran effects (synchronization of population dynamics between distinct populations in response to shared external factors) in accounting for adaptive synchronicity among maritime HG´s in Fennoscandia, and in paper 4, when positing environmental drivers of the convergent evolution of maritime slate technologies across the circumpolar region (in direct opposition to Gjessing). An additional point to stress here, is that paper 4 was motivated by applying a adaptationist account of the slate industry and thereby follow up on what was initiated by W. Fitzhugh´s now age old study of functional properties of Scandinavian slate complexes (Fitzhugh 1974). Paper 4 elaborates on his study by developing a causal framework for explaining how slate technologies contribute to increased adaptive fitness. This was necessary, as other treatments of slate technology in the area have emphasized aesthetic and ritual aspects. Yet the fact that a technology is maintained for millennia among a small population can only mean one thing from an evolutionary perspective: "if we find what appears to be a small population maintaining some cultural attribute over a very long period of time, it suggests that it is taking strong measures to ensure its continuity or that the attribute is contributing a strong selective advantage" (Shennan 2000:815). Strikingly illustrating my point, the long-term maintenance of slate technology has previously been taken to imply cultural stability and continuity (in the sense of social identity and group persistence), as argued from culture-historical homology. To the contrary, I have tried to demonstrate that such accounts carry little explanatory clout as they disregard the adaptive basis for maintaining any practice over considerable time and space, while also fail to account for important variations in how the technology was deployed.

2.4 Environmental determinism?

What I am trying to get at through my project are the dynamics of human and environmental relations. Yet by criticizing previous research for assuming a strong tendency of equilibrium and continuity such relations, viewing past populations as more or less emancipated from the environment, I necessarily have to assume that past populations somehow were subjected to external factors beyond their control. Does this mean I run the risk of invoking environmental determinism?

If, as Brooke (2016) claims, “Environmental determinism argues that both general features and regional variations of human cultures and societies are determined by the physical and biological forms that make up the earth’s many natural landscapes” – then I am partly guilty as charged, but so is most of archaeology. Strictly defined “environmental determinism occupies one end of a continuum, cultural determinism occupies the other; each argues that the human condition is determined simply by nature or simply by culture” (Brooke 2016). In practice, very few maintain such exaggerated positions. What people disagree over is the relevant *degree* (relative proportion) to which environmental factors account for the diversity of the human condition (Arponen et al. 2019:22). The importance of environmental drivers in human adaptation and cultural evolution is well-established in the global archaeological literature, and arguably, *a priori* conditional on the environmental embeddedness and biological nature of human beings. Disregarding this fact in macro-scale explanatory accounts would miss out on a relevant and potentially significant, confounding variable.

Initially, I was not committed to any school of thought as a repository for hypotheses or analytical concepts. In practice however, I ended up emphasizing a strongly Human Behavioral/Historical Ecology (Bates 2012; Kennett and Winterhalder 2006) approach to the reconstruction of past human interactions with Arctic ecosystems. On multiple occasions during my work have I been accused of presenting/invoking an eco-deterministic position. Personally, I do not find such remarks troubling, as it is obviously false. From a professional perspective, however, I find such critique to be the expression of widely held misconceptions concerning the applicability of ecological theory to the human species. I have always found such criticism puzzling, because archaeology to me is essentially the extension of historical and evolutionary ecology to also include the human species. There is still considerable surplus left in the archaeological discipline beyond human ecology before it is reducible to environmental determinism (e.g. our unique interest in material culture and formation processes of the archaeological record). Regardless of misconceptions, such as Shanks and Tilley´s (1987:154–5) claim that “most social and material practices have no demonstrable physical survival value for human populations whatsoever”, ritual and symbolic behavior is in no way incommensurate with the predictions or analytical framework of ecologically oriented archaeology (such as HBE/H.E.). The only, and crucial difference, is that under this analytical regime seemingly non-functional behavior is explicable by reference to basic behavioral drivers rather than being dismissed or celebrated as inexplicable particularism/uniqueness. Costly signaling, is a telling example, whereby “wasteful” traits apparently evolve at the expense of adaptive fitness, yet actually increases reproductive fitness (see Salahshour 2019). The peacock’s tail being the classic case, as it reduces flight capabilities (great cost) but is decisive in attracting mates (increases reproductive success).

In terms of research history, processualism (by proxy of functionalism) came under critique of being environmentally deterministic and thus explanatorily biased by a number of post-processualists (e.g. Olsen 1997:133; Shanks and Tilley 1987:153). Given the increasing popularity of environmentally driven research agendas, a similar, critical response to the scientific archaeology of the new millennium might also hold true. Does this environmental and adaptationist focus entail a naïve determinism? Such worries have been raised by Arponen et al. (2019), claiming that recent studies of human/environmental interactions that report coincidental trends among cultural and environmental variables/time-series often rely on over-simplistic assumptions of causality, on the point of mindless environmental determinism. As succinctly pointed out by Ion (2019) in response to Arponen et al., no level of empirical resolution can ultimately solve the issue of causality. Reminding the reader of

Hume´s deliberations should be sufficient to drive home this point. Instead, Ion (2019:11) posits that the foundational problem is one of applying oversimplified hypotheses - that is, not asking the right questions. I wholeheartedly support her rally "to design more complex interpretive models, which allow for multiple factors to be integrated. At the same time, especially for the prehistoric past, we need more data points and precise dating techniques that would allow for refined connections" (Ion 2019:11). This resonates with my ambition of fleshing out the middle-range of archaeological abstraction levels by integrating the micro and macro level. This is easier said than done, but in practice, it involves designing projects that willingly accept the responsibility of conjoining even the most minute empirical detail with the generalized expectation of patterned data into a scalable whole.

I think most would agree that what needs to be avoided are mono-causal explanations. Deterministic accounts are essentially mono-causal in emphasizing one variable exclusively at the expense of all others. The alleged environmental determinism of scientific archaeology or the cultural determinism of humanistic archaeology are mirror images of the "two cultures" debate in science in general. However, there exists a unifying concept able to encompass the scientific ambitions of archaeology without having to compromise on historical particularism of past states – which is defining archaeology as a "historical science". Historical sciences are separate from the experimental and formal sciences in fundamentally studying change and process. By this conception, archaeology fits together with geology, palaeontology, astronomy, evolutionary biology and historical linguistics (Cleland 2001, 2002, 2011; Davidson 2010; Lyman and O'Brien 1998; cf. Jørgensen 2015:136). I elaborate on these issues, not merely as an exposition of my fundamental stance within philosophy of science and archaeology, but also because critical reception of this position has been a recurrent theme during my PhD work.

3 Research design: From parts to the whole

This thesis was built around a research design answering to the particular research objectives stated in [Section 1.1.Overall ambition]. Here I elaborate on the research design, focusing on how the individual papers contribute building blocks to the coherent whole of the thesis. As is hopefully communicated through the papers, there is a particular logic to the progress of my work. This logic is based on a small number of guiding principles.

3.1 Initial expectations and final design

When applying for the PhD-position, and later, when initiating my research, I developed a research design in line with the expectations of the "Stone Age Demographics" research group. Important aspects of my research focus were already a given. Thus, a few notes on the background for my position and functional role within the research group is appropriate.

My project was designated with solving a particular issue on behalf of the larger project group:

- Produce demographic models for long-term, large-scale population fluctuations

In addition, and in concert with other members of the group, the following issues overlap with my project:

- Explore regional settlement variation and local site use
- Analyze the correlations between demography and environmental and socio-cultural transformations

However, certain elements of the original plan have been abandoned, refined or changed. Thus I believe it useful to recapitulate somewhat in order to account for the actual progress compared to initial plans and the evolution of research focus in accordance with the accumulation of results.

What becomes evident from reviewing the initial research design and comparing it with how it all turned out, is that the focus shifted away from the critical evaluation of methods of palaeodemographic reconstructions, in favor of a more holistic H.E. approach. There were good reasons for making this shift. The way I have viewed this with increasing clarity during my work, is that parts of the original design, which included an attempt at making methodological contributions, were naive and unfeasible. I am in no way a methods specialist, and particularly not within what has become a genuinely specialist topic for statisticians and mathematicians.

Beyond these adjustments to the research plan, I have had multiple excursions ("detours" seems too strong a word here) into related, yet unsuccessful avenues. For instance, I spent a lot of time trying to establish an empirical nutriscape of human/coastal interactions, from the ground up. This led me into rabbit holes of ecological and climatic research, reading up on the complex ecosystem interactions between physical oceanography, coastal biochemistry, marine trophic relations, trying to map current and reconstruct past biogeographic distributions of various fish and sea/terrestrial mammal species, as well as settling into the ethnography of circumpolar maritime hunter-gatherers. The multi-facetted character of human ecodynamic research has truly been staggering at times, something I was confronted by when I at one point ended up reading a paper on variation in the density of penguin droppings in an Antarctic lake, while nodding approvingly, assured of the relevance to my own work.

Furthermore, I have spent a significant amount of time reading about capelin as a "keystone" species in the Barents Sea ecosystem. The ambition of establishing a human/coastal nutriscape turned out to be undoable given the lack of representative archaeological and ecological data. I also reviewed palaeoenvironmental and –ecological data to rectify this, however, there is almost a complete lack of reported archaeofaunal remains from non-archaeological sites (such as geological, bog cores etc.). Although neither penguin (droppings) nor capelin (beach-spawning behavior) ended up in print, such thematic excursions have been the privilege of focused study that informs the (mostly silent) corpus of knowledge necessary to engage in multidisciplinary research.

A final development that should be mentioned briefly is that I started out agnostic about the validity of the summed probability distribution (SPD) methodology in palaeodemographic modelling, and have been rather apologetic of its merits for most of my time in the field. Keep in mind that there is an important aspect to the historical timing and context of this dissertation. When I started working this project (2016), the debate over whether SPDs were the solution to all our problems or, alternatively, wishful thinking in the form of statistical mumbo-jumbo, was at its intense peak. The fairly harsh and irreconcilable debate between Torfing (2015) and Timpson et al. (2015) had just been published, and was only one example of the dispute over the validity of reinvigorating palaeodemography (Contreras and Meadows 2014; Mökkönen 2014). This made for a turbulent yet exciting time of entering academia, particularly when taking part in the (re)emergence of a new field.

My vague reservation towards the methodology (that I did not sufficiently understand at the time) has gradually disappeared. An anonymous reviewer of one of my papers questioned my slightly indecisive attitude towards SPDs. The reviewer pointed me to important studies going far towards qualifying the method, such as (Edinborough et al. 2017). I was eventually convinced by the consistency of patterned results across larger regions, e.g. the synchronous population dynamics across mid-Holocene Europe. This was further corroborated by my own work, as comparative studies with other regions demonstrated remarkable synchronicity (paper 3 and 4). Today, the archaeological community is still split in its attitude towards the prospects and merits of palaeodemographic modelling. However, the skeptical camp has been spectacularly unsuccessful in coming up with resilient objections that disprove, or even negate, the lasting value of palaeodemographic modelling to some of the most long-standing issues in archaeology. My opinion on this matter is that the majority in the skeptics camp align with the broader clan of archaeologists fundamentally skeptical of quantitative analyses in general, and in particular overlap with those that reject the ambition of an archaeological science out of hand. Although the method is imperfect and can produce false results, that is the nature of all methods and has more to do with naïve application and/or posing ill-fit questions. What constitutes good science, however, is the relentless drive for improvement through critical examination, adaptation and overcoming current boundaries. The future of archaeology is increasingly technical and specialized. Holding on to qualitative single-proxy investigations will not take us much further.

3.2 From exploratory to explanatory

Given my designated role in providing the overall/superregional trends in demographic and environmental trajectories for the "*Stone Age Demographics*" project group, this was the natural starting point of my enquiry. Such work had not previously been attempted in the region beyond the early cases from Finland (Tallavaara et al. 2010, 2015; Tallavaara and Seppä 2012), necessitating an exploratory approach. *Exploratory research* may easily be written off as the hallmark of pre-paradigmatic sciences. Largely, this is the case in archaeology, more often than not confined to *exploratory* or *descriptive research*. Although *explanatory/causal research* should be the ultimate goal of any scientific enterprise, this level of inquiry is often problematic to get at in archaeology. This mimics the dynamics in which qualitative research constitutes the initial (exploratory) identification of relevant problems to be tested quantitatively on larger, more robust and generalizable samples. The first paper mainly consists of pattern recognition and testing what the available data might tell us. This would form the basis for further investigations and what to prioritize. Several significant population cycles were identified. Two of these were selected as case studies for later papers as it is not possible to make detailed ecodynamic investigations of the entire Holocene at once.

Following the identification of macro-scale human ecodynamic patterns, it was possible to move into more explanatory and problem-oriented research. On the basis of a reductionist scientific outlook postulating that macro-scale entities (including the social realm) are best explained through reduction to their constituent parts, merely identifying macro-scale patterns would not amount to any "explanation", or be intellectually satisfying for that matter. However, such pattern recognition is the unavoidable first step towards developing causal explanations.

3.3 Scalability as structure

Answering to the overall ambition of my work, giving primary attention to the demographic variable helps integrate a multitude of other variables in multi-scalar investigations and allow for the production of *scalable* explanations. What is meant by this? A scalable explanation is one that is "global" in the analytic sense, transcending the particular scale of investigation in functioning either as a building-block at the higher level or as generalizable predictive theory at the lower level. That is to say, that the performance/suitability of a design is maintainable also when applied to shifting scales of operation. As demography permeates all aspects of human societies, any investigation into the palaeodemographic dynamics of a given area should aim at linking various scales (both analytically and in terms of the empirical human ecodynamic trends) in order to produce successful accounts.

In this regard, "scalability" has been the primary principle guiding my research design. This is also a necessary requirement of reductionism - explaining higher-order phenomena by reducing them to their lower-order constituents. This is ensured by the papers addressing various aspects of what is in truth a multi-scalar, human ecodynamic phenomenon. The scaled properties of and interrelations between the individual papers are illustrated in (Fig.6).

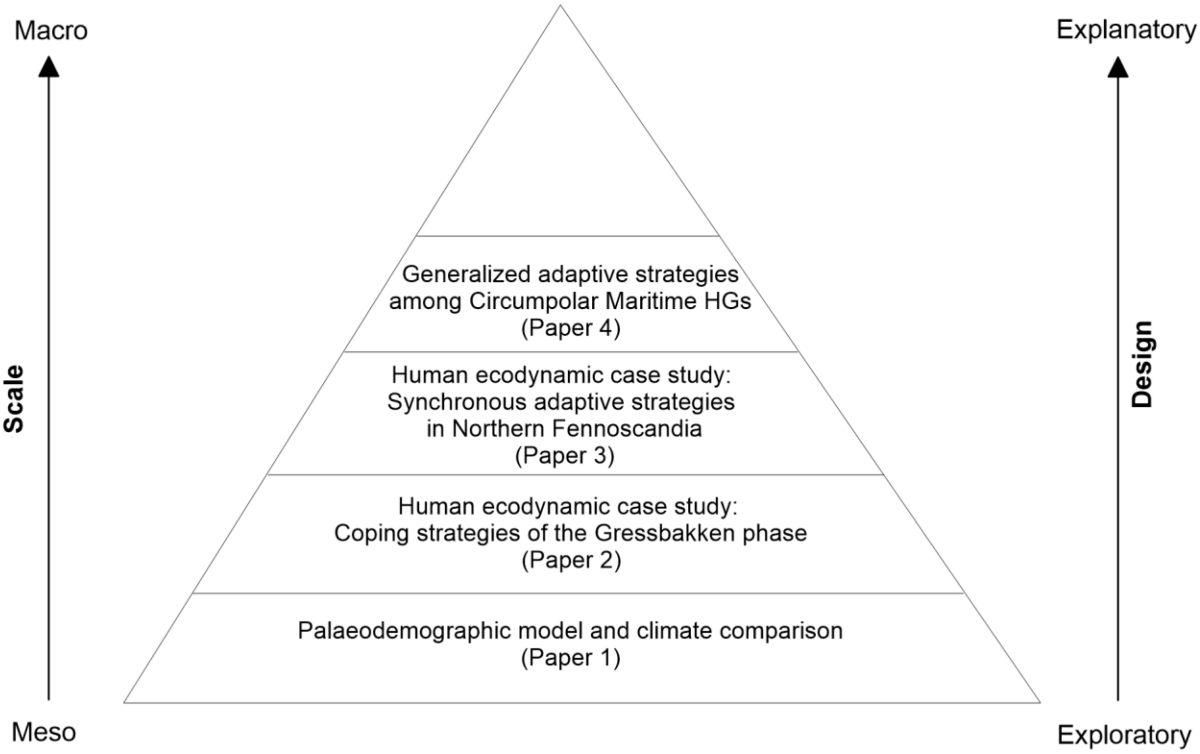

Figure 5 Relation between papers and scalability of research design

Paper 1 answers most directly to Research Objective A (Reconstruct relative population size changes through time) by reconstructing relative population changes, through radiocarbon-based palaeodemographic modelling. Besides identifying long-term trends in human demographic variation, the paper also maps their covariation with environmental dynamics – answering to Research Objective B (Compare with relevant palaeoenvironmental records). A major result of the first paper was the identification of a general, increasing population trend across the Holocene, including three significant, positive boom-and-bust cycles, centered on 5800, 4000 and 2200 cal BP. The overall demographic trend makes a superb starting-place for further investigations into the particular characteristics of the dynamics. The identified cycles were supported by similar patterns more broadly identified in the European context. On the basis of this exploratory research and successful identification of significant variation, it then became necessary to investigate the possible causes of the observed variation. If, instead, the initial study had produced static patterns, this would chart a very different course. A highly significant contribution of my work has therefore been to increase the awareness of the *dynamic* nature of population level human demography, and the frequency with which major population fluctuations occur. I have stressed the fact that high-frequency demographic change and abrupt, as well as gradual, population fluctuations are the norm rather than the exception. Paper 1 set the stage for the other papers, not only in the sense of providing the empirical groundwork to be analyzed in more detail, but also by firmly establishing the agenda of developing mechanistic explanations of human ecodynamic relations: "The causal mechanism connecting climate variability (ultimately driven by solar insolation) and human demography may therefore be more explicitly defined as: *the aggregation of climate effects up through local and relevant food webs, eventually affecting human nutrition and reproduction*" (Jørgensen 2018:12). This became the thread of continuity throughout all of my papers.

Paper 2 makes a dive into an intermediate scale, being essentially a case study of the 4000 cal BP population cycle in Arctic Norway identified in paper 1. It attempts a scalable account of a particular population event and its causal drivers and consequences, with main emphasis on the coping strategies of the local population during repeated environmental perturbations (Research Objective C: Provide detailed case studies of human adaptive responses to ecological change). Highlights of this investigation are the abandonment of semi-sedentary and larger coastal sites in favor of increased mobility and inland resource exploitation following a set of climate deteriorations 4000-3500 cal BP that induced decline among both human and reindeer populations. This paper and the project in general, contributes important balance to the prior emphasis on internal factors, by exploring the ecological and adaptational drivers of change among the past populations of prehistoric Arctic Norway. This has been done by extensive comparison between demographic modelling results and relevant palaeoenvironmental records (Research Objective B). Most importantly, the results demonstrate strong trend correspondence between palaeodemography and environmental trajectories.

Paper 3 takes on a more scalable approach. It is both a regional case study of the 6000 cal BP population event in Arctic Norway while also providing important comparative analysis across northern Fennoscandia. It demonstrated remarkably synchronous demographic and adaptive changes among geographically disjunct populations in Arctic Norway and Western Finland 6000 cal BP, with increased reliance on coastal lifeways, apparently driven by a shared increase in marine productivity. This is possibly the most direct and explicit demonstration of the Moran effect among prehistoric human populations in the global literature so far. In establishing middle-range explanatory mechanisms (Research Objective D), paper 2 attempts a bottom-up explanation of how risk reduction strategies and adaptive responses of the population had large-scale effects, while paper 3 employs population ecological theory to explain synchronous trends across large geographical areas. Paper 2 and 3 thus are the direct answers to Research Objective C in providing detailed case studies of human adaptive responses to ecological change. However, the results are made all the more important and interesting as they demonstrate ecosystem-specific correlations between demographic and environmental trajectories. Specifically, the coastal population has been shown to be more strongly regulated by changes in the marine environment, than that of the terrestrial. As such, this work has contributed to an increased understanding of coast/inland dynamics of prehistoric Arctic Norway.

Paper 4 contributes overall integration and at the same time, a deep-dive case study of the 6000 cal BP population event, and its relation to the emergence of a long-term tradition of ground slate technology. The modelling results, climate comparisons and results from reviewing trends in the archaeological record were integrated in a multi-scalar analysis. The importance of this lies in being able to identify adaptive strategies in mitigating/responding to and coping with/benefiting from environmental changes. This was investigated in greatest detail concerning the strong trend correspondence not only between demographic trends of the coastal population and the primary productivity of the local coastal environment, but also with the introduction, development and final decline of the ground slate industry. The positive identification of correlated relations between environment, demography and technology gets to the very core of human ecodynamic research, and arguably, archaeology at large. The dissertation comes full circle with this paper, as it integrates and expands upon issues not fully resolved in the other papers. Here I made considerable effort at 1) identifying, 2) explaining and 3) coupling the variables of the respective human ecodynamic system. Then I could delve into the explanatory realm, mostly relying on population ecology models, and develop a new causal framework for explaining properties of the ecodynamic trends and events demonstrated in the previous papers. This also allowed making a general, analytic contribution to the broader field of archaeology and human ecodynamic research. Paper 4 is therefore the most “scalable” contribution, spanning the level of morphometric analysis of individual tool types to population ecological explanations for convergent evolution among circumpolar maritime hunter-gatherers, answering to Research Objective E (Track the evolution of maritime adaptation in the region.).

3.4 Middle-range causal mechanisms

This thesis has from the very outset been occupied with exploring human/environmental relations in Holocene Arctic Norway. Yet it was not predetermined how this best could be operationalized in a research design. In this regard, I have tried to comply with what was stated more than 50 years ago by Binford:

> "*changes in cultural systems must be investigated with regard to the adaptive or coping situations which are presented to human populations. If we are profitably to study process, we must be able to isolate cultural systems and study them in their adaptive milieu conceived in terms of physical, biological, and social dimensions*" (Binford 1964:426).

The prospects for realizing Binford´s agenda used to be rather bleak, as neither "process", "isolating cultural systems" nor to "study them in their adaptive milieu" could get very far without solid, empirical baselines of change in the physical, biological, and social dimensions, respectively. Through my papers, I have therefore been concerned with establishing long-term timeseries in both the cultural and natural domains, and in this way construct the necessary baselines for the study of change. However, what epitomizes the research agenda put forth by Binford is the identification of middle-range causal mechanisms. Beyond constructing baselines for the study of change, all of the dissertation papers have tried to identify and dissect plausible middle-range causal mechanisms responsible for the observable human ecodynamics.

The title of this dissertation includes the phrase "developing middle-range linkages" between various system components of the human ecodynamic system in question (Holocene Arctic Norway). Note that this is "middle-range" mostly in the Mertonian (sociological) sense of unifying "general theory" and empirical research by identifying core causal mechanisms (Merton 1968; cf. Hedström and Udehn 2011), rather than in the Binfordian (ethnoarchaeological) sense of linking observable behavior to the interpretation of the archaeological record (Binford 1977:1–10; Raab and Goodyear 1984). The middle-range ambition, as construed here, is similar to that of Trigger´s description of various levels of generalization (Trigger 2006:31). It has not been possible to complete this endeavor to the extent that I would have liked, as my contribution is but one piece within the larger research project subject to a functional division of labor. My function has primarily been to establish macro-level patterns, but I have attempted to extend my reach into the meso-level, as this is where the magic happens. Fully integrated and multiscalar syntheses are planned for the total project in 2021-2.

A major ambition of my work has been not just to relate large-scale climate fluctuations and demographic responses, but just as much to develop middle range mechanisms for understanding the mediation of large-scale environmental variability through local ecology, impacts on human demography and adaptive strategies and potential feedbacks. This is illustrated in (Fig.7).

Although large-scale climatic conditions are a macro-scale aggregate, they (mostly) act upon the components of human ecodynamic systems through bottom-up processes, that is; through regulating environmental productivity and trophic connections in an ecosystem including humans. There are, however, some cases in which climatic conditions produce top-down human demographic effects without mediation through lower-order trophic levels, e.g. natural disasters. Throughout my papers I have tested for the impact of both gradual and abrupt environmental changes. A most specific example is paper 2, when investigating the dynamics of a single human ecodynamic cycle. Particular focus is directed at the risk-mitigation responses of the population to a series of environmental perturbations, and ultimately at mapping the likely impact of the ultra-distal Thera eruption on the Arctic Norwegian ecosystem (Jørgensen and Riede 2019).

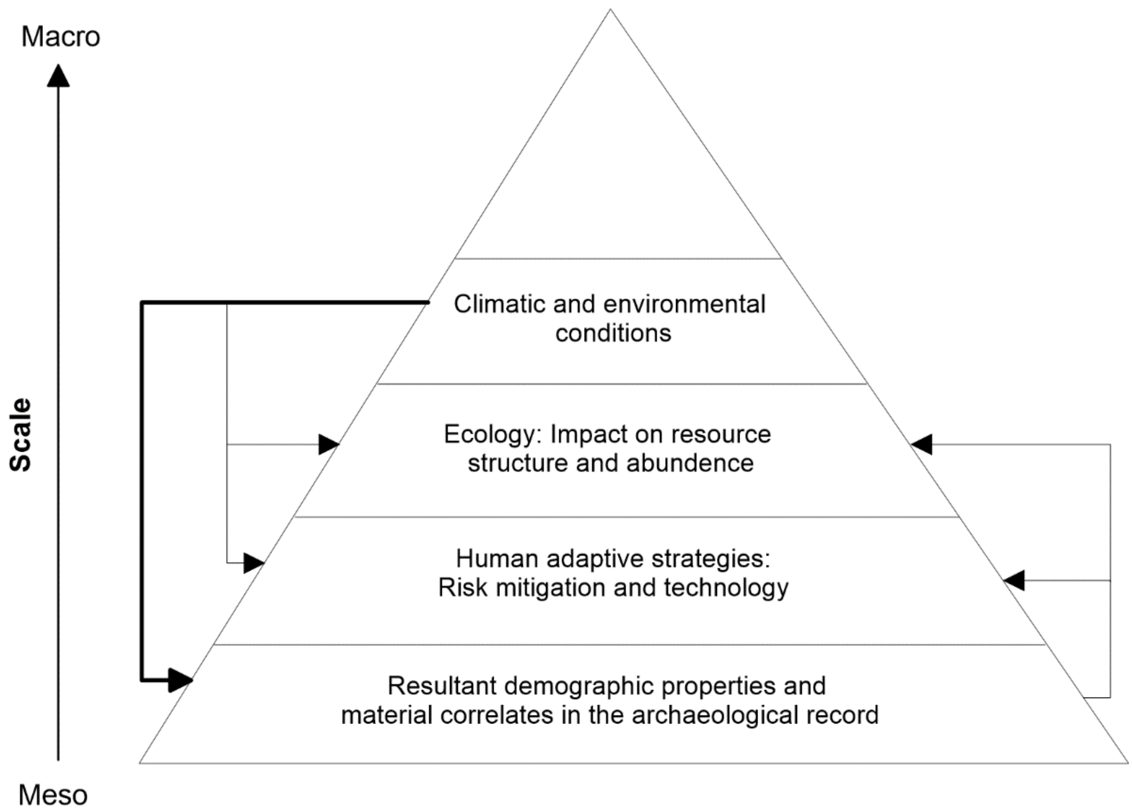

Figure 6 Causal linkages in human ecodynamics research.

The importance of establishing middle-range mechanisms is further stressed by the fact that the "study of present-day phenomena and conditions can provide sound analogies for understanding the *structure and mechanisms* of systems of many kinds, including the planet's climate and biological cycles. However, analogies cannot be used directly to posit *system states* in the past or future" (Dincauze 2000:34) – emphasis added. Thinking about this more closely reveals (at least to me) why archaeology is anthropology and not history, sensu Binford (1962). We seek to understand general mechanisms, not so much particular states of past affairs – although the latter is closer to the popular conception of what archaeology is about.

4 Methods and materials

Here, the methods used to analyze data in this dissertation are briefly presented. See the individual papers for a full review. This section is more concerned with providing additional background materials and methodological considerations that for various reasons could not be presented in the published papers. The main purpose of this section is to provide a critical consideration of the North Norwegian Radiocarbon Database, as it forms the most important dataset of this thesis.

4.1 Are palaeodemographic proxies trustworthy?

The results of my work fundamentally rely on the summed probability distribution (SPD) methodology, which has become the leading tool for reconstructing long-term population change in archaeology. SPD analysis is a statistical technique for modelling the relative change in population size in timeseries on the basis of archaeological radiocarbon dates. The density of dated archaeological events per time unit is assumed to correspond to the density of past populations – which is the foundational premise built into the SPD-method of the so-called “dates as data” or “more people, more stuff” theorem. The theorem assumes an *ahistorical* constant of a linear correlation between population number and the deposition rate of datable materials (Rick 1987; see also Haynes 1969; Holdaway and Porch 1995; Kirch 1980). The history of the dates-as-data theorem has been thoroughly reviewed in (Tallavaara 2015:19).

SPD analysis proceeds through collapsing the probability distribution of individual radiocarbon dated human activity events into a combined probability function of N dates. The output is evaluated in terms of relative population densities, and population dynamics are inferred from the topography of the probability distribution. The method saw substantial progress through the development of a means of statistically testing the significance of the observable fluctuations, presented in (Shennan 2013; Timpson et al. 2014), as well as the simulation procedure developed in (Contreras and Meadows 2014), which have become commonplace through the software packages in the R-language (Bevan and Crema 2020; R Development Core Team 2015). The SPD results are compared to a statistical envelope null-model, in which randomized calendar dates sampled from the distribution defined by a null-model are back-calibrated into radiocarbon dates. A number of simulation runs (N_{sim}=1000) are performed in the production of the statistical envelope making the random “background noise” (Crema et al. 2016:5). Any deviation outside the 95% confidence interval of the envelope null-model marks the SPD results as statistically significant under the null-hypothesis of either uniform or exponential growth.

The SPD methodology shares the dates-as-data theorem with classical population historical estimates based for instance, on skeletal remains, the density and number of sites or habitation features, the quantity of lithics and pottery etc. Still, SPDs arguably provide a more direct proxy for a wider range of population-related activities and are less obstructed by the issues hampering other palaeodemographic data sources in not discriminating temporally, spatially or typologically bounded activity indicators (as is often the case with other proxies). The only criteria for inclusion is that organics of cultural origin have been dated. The theorem posits that the deposition of datable materials per person is rather uniform and constant regardless of situation. Intuitively, the depositional rate and -character of any population are highly contingent phenomena, depending on activity, technology, subsistence, mobility, settlement pattern, waste management norms and social taboos to name but a few. Thus, *qualitatively* one might expect a fully sedentary Neolithic farming community to produce a very different depositional record compared to small groups of highly mobile, Palaeolithic hunter-gatherers. Yet the theorem posits that the *quantitative* character of the depositional record per person would be more or less constant between the two examples. This has sparked some controversy as, to some, this is difficult to accept. What has caused considerable debate, and has often been criticized, is precisely the dates-as-data assumption. The critique ranges from the constructive to downright dismissive (Attenbrow and Hiscock 2015; Mökkönen 2014; Contreras and Meadows 2014; Torfing 2015).

However, a detailed reconstruction of historical population trends using various demographic records, produced striking correspondence between actual and modelled demographic trends (Edinborough et al. 2017; see also French 2016). A sedentary community might produce large deposits of datable material in one place, while a mobile community might produce minor refuse concentrations highly scattered across the landscape, but in the end this evens out into comparable signals in the radiocarbon record given equal population sizes. One might object that the depositional structure of any population creates differential conditions for preservation in itself, as the remnants of the innumerable campsites left behind by highly mobile Palaeolithic populations very rarely gets preserved. This runs counter to the increased likelihood of datable materials being preserved at sedentary settlements, as midden deposits and culture-layers tend to accumulate and enhance organic preservation in and of themselves. Despite this objection, the theorem suggests a balancing-out of depositional signals over the long run. The protocol for date combination (when multiple dates are available from a depositional feature) is also meant to counteract such overrepresentation of well-preserved samples. Consequently, it does not matter how many age determinations are made on a deposit when the dates are combined into age bins prior to SPD analysis. The binning protocol is discussed in [Section 4.4].

The recent popularity of palaeodemographic research has been on the receiving end of critical responses from multiple directions. At least three critical camps can be identified as more or less outspoken against the approach taken here. 1) Those that reject its validity on methodological grounds (discussed below). 2) Those rejecting the need to explain macro-scaled phenomena in the first place, by appeal to the idea that human actors and their consequences should be the object of archaeological inquiry by way of a historical accounting of events and explanatory minimalism. 3) Those critical of the scientific value of using SPDs for "mere" pattern recognition without rigorous statistical testing – thus questioning the value of SPDs as a basic descriptive exercise without explanatory power. The latter criticism would have been relevant were it not for the explicit ambition of providing regional case studies as building blocks that can be aggregated into larger, more robust and generalizable samples. Thus, I find such criticism badly misses the target. Instead, I view the trends of human ecodynamic and palaeodemographic research as strong candidates for greatly advancing archaeology as a scientific discipline. The heuristic value of compiling long-term trends on the basis of big datasets is either way great as a starting point for identifying crucial variables, tentative causal connections, as well as for pinpointing weak spots in current datasets.

The scarcity of alternative demographic proxies that also are quantifiable in the study area is a weakness. It would have been preferable to copy the design of other studies that compile and compare various archaeological demographic proxies, such as (Palmisano et al. 2017). This has not been feasible, mainly for two reasons: 1) lacking good chronological and typological resolution of useful material culture categories (although paper 4 decidedly is an attempt at remedying this), and 2) the division of labor between different members of the "*Stone Age Demographics*" research group, in which radiocarbon-based demographic modelling has been my designated subject. One promising avenue here is counting and binning of coastal house features by shoreline displacement, used as an independent demographic proxy of the ^{14}C record. A small-scale study of this is already underway by other parties of the research group (Damm et al. in prep). Ideally, this should be extended to the entire Arctic Norwegian coast and correlated with radiocarbon-based palaeodemographic modelling, were it not for the thwarting effect of both a) the significant isostatic differences currently undercutting reliable comparisons of shoreline displacement dating across larger spatial scales, b) the minimal uplift throughout the mid-Holocene resulting in intense reuse of stable beach-ridges, as well as c) the partial transgression of the outermost coast in the northwestern area, which has erased or buried sites.

4.2 Critical issues in palaeodemographic modelling

Major efforts have been made to identify and remedy analytical and computational weaknesses in the modelling of past population dynamics. Here I list important factors that have been discussed. As stated earlier on the evolution of my research project [Section 3.1.], trying to resolve these issues is beyond the scope of my work. The function of this review is rather to demonstrate the necessary understanding of potentially biasing factors before I turn to an in-depth evaluation of the local radiocarbon dataset below.

Reservoir effects

Due to significantly slower turnover rates of carbon cycling in water basins than in the atmosphere, there is an offset between marine and terrestrial carbon. This introduces artificially old age in the radiocarbon dating of aquatic carbon. The reservoir effect is particularly large north of 40° latitude, with increasing deviation with older dates. The reservoir effect is a local product of oceanographic and hydrological conditions and thus, local corrective measures are necessary. The standard marine reservoir effect in the area is 420 years. However, a freshwater reservoir effect spanning several millennia have also been demonstrated and pose a serious threat to determining the age of inland, aquatic resource exploitation. This has led to a preference for using the carbon of short-lived terrestrial origin in dating protocols, whenever possible.

For general description of the problem see (Jull et al. 2013). On freshwater/hardwater reservoir effects in archaeology, see (Philippsen 2013; Philippsen et al. 2010), as well as freshwater reservoir effects in terrestrial mammal bones (Philippsen 2019). For global marine reservoir calibration curves, see (Hughen et al. 2004; Reimer et al. 2013). For local marine reservoir effects on the coast of Norway, see (Björck et al. 2003; Mangerud and Gulliksen 1975).

The old wood problem

The inherent age of the material used for dating introduces imprecision and potential biases. Charcoal is the most frequently dated archaeological material, yet without knowing the life-span of the material prior to charring and dating, the dating results become unreliable. This produces a bias towards excessive antiquity, particularly in areas with minimal local terrestrial growth and rich in drift-wood – as is most common in high latitude regions. This has led to the emphasis on short-lived terrestrial materials for dating and the standardized procedure of wood species identification and sample selection by a dendrotaxonomist. Seminal works on old wood issues in archaeology are (Dean 1978; Schiffer 1986). The old wood problem has a particularly long research history in southwestern US, pueblo archaeology. A related problem is also known from marine contexts, such as the “old shell problem”, resulting from the spectacularly old age of particular bivalve species introducing significant uncertainty in dating (Rick et al. 2005).

Calibration

A critical bias can be introduced by radiocarbon calibration, as the “non-linear relationship between the calendric and radiocarbon timelines may introduce anomalous structures into radiocarbon-supported temporal frequency distributions (tfds)” (Brown 2015:133; cf. Buchanan et al. 2008:11651). This was most directly discussed in (Michczyński and Michczyńska 2006). The most critical aspect is that of radiocarbon plateaus, which result in high uncertainty connected to dates falling within the range of the plateau as it may conflate actual results by a sink-effect - attracting disproportionally amount of dates. In the opposite case – steep slopes in the calibration curve may distribute actually associated dates over a greater time-span. Williams (2012:582) has identified 17 plateaus during the last 50 kya, with an average timespan of 770 years, though fortunately the more extensive plateaus occur during 30-50 kya. “plateaus within the Holocene are generally constrained to only a few hundred years” – averaging at 483 years.

Sampling bias / Binning

Excavation and sampling practices may introduce bias into the radiocarbon record. Favored research topics that receive disproportional amounts of attention, are prone to make a disproportional contribution to the radiocarbon record. Some areas and periods are much more intensively dated than others (e.g. much effort has been put into dating the Meso/Neo transition throughout Europe, resulting in an overrepresentation in the radiocarbon record (Crombé and Robinson 2014)). It is therefore necessary to vet all datasets before palaeodemographic modeling. The most important countermeasure in this regard is the process of “binning”, discussed in [section 4.5]. Dates from the same site that fall within 200 year intervals are combined. This normalizes the unequal contribution of various sites (e.g. by skewed sampling) to the radiocarbon record by reducing the multiple radiocarbon dates are to a single probability distribution. The procedure for combining clusters of dates to minimize the over-representation of intensively dated sites in current practice is described in (Shennan and Edinborough 2007:1341). For earlier takes on the matter, see (Ward and Wilson 1978). An alternative approach has also been presented in (Steele 2010)

Taphonomic bias / Curvilinearity of ^{14}C datasets

SPDs operate on the face value of the underlying radiocarbon dataset. The method therefore assumes an equal rate of preservation from all periods and regions, while differing taphonomic agents may be both spatially and temporally contingent. Even changes in prehistoric behavior may greatly affect the amount of preserved materials (e.g. switching from inhumation to cremation burials, depositional practices, changing landscape preferences – different preservation conditions at the coast and inland). The preservation of charcoal is of special importance to the SPD method and dates as data-approaches, and has received some attention in this regard, see (Théry-Parisot et al. 2010). Taphonomic bias has seen multiple demonstrations in terms of positive curvilinear trends in long-term radiocarbon frequency distributions, in which “older dates exist in lower numbers than more recent dates, which in part reflects the removal of cultural carbon from the archaeological record through processes such as erosion and dissolution” (Peros et al. 2010:656). Such curvilinear trends may easily give the impression of exponential population growth. A solution has been devised in “taphonomic correction”, whereby the SPD is normalized on the basis of the empirically observed exponential rate of taphonomic loss through time (Surovell et al. 2009; cf. Surovell and Brantingham 2007).

Sample size / Accuracy in dates

What constitutes sufficient sample sizes of 14C dates for SPD analysis fundamentally depends on the time interval under scrutiny, as demonstrated in (Michczynska and Pazdur 2004; Williams 2012:581) and discussed in greater detail in [section 4.5]. The critical issue is achieving sufficient data density for any given interval. What constitutes sufficient density is also dependent on the accuracy of the dataset, in terms of the mean laboratory error of the dataset. The lower mean laboratory error and the higher the number of dates per interval, the more robust the results. Yet, it has been demonstrated that significantly smaller samples are able to pick up on overall trends. In general, the precision of recent dates is much higher following the advent of AMS dating over conventional Beta counting. Bamforth and Grund (2012) produced an important test of the impact of using different calibration curves on the modelled results and demonstrated the importance of robust sample sizes.

Mobility bias/ Non-linear scaling of area use

Increased mobility will result in a higher number of sites and, potentially, more datable materials – affecting both site counts and 14C SPD: "Increased mobility (which would appear as peaks in the 14C date distribution) is a common buffering response amongst hunter-gatherers in the face of resource uncertainty and decreased productivity induced by climatic cooling" (French and Collins 2015:128–9). What may look like increasing population numbers, may only reflect the relocation of a population into smaller areas, as has been demonstrated for the population peak and trough 15-14K in Southern France, as the area became a refugium during the last glacial maximum (French and Collins 2015:128). This issue would question whether the "more people = more datable stuff" relation actually is linear. This would result in the need for a weighting factor, compensating the decreasing amount of datable materials left behind per person, as the number of people increases. This has been discussed in relation to area-use per person. Hamilton et al. (2007) demonstrated "a nonlinear scaling relation between area used per individual and population size. [Whereby] the scaling exponent is less than one, so the area required by an average individual decreases with increasing population size, because social networks of material and information exchange introduce an economy of scale". They show that the "more people-bigger site size relation" may not be linear, and by implication, so is not the "more people-more stuff" relation. However, this is not evident in the Binford (2001:241) database. See also the evaluation concerning how well the amount of datable materials correspond to past population numbers in (Hinz et al. 2012). See also the classic work by Kent (1991:36–39) concerning the relationship between mobility patterns and site structure.

Site types

The definition of a "site" to be included in a site distribution is of importance, as it has been debated what kind of sites should be included, as non-habitation sites may artificially increase the number of sites and thus inflate the population model. Should isolated fireplaces be included on the same basis as dwelling features? For examples and discussions of this issue, see (Bird and Frankel 1991; French 2016:167; French and Collins 2015:131; Straus et al. 2000; Yellen 1977:78).

Site size and contemporaneity

It is difficult to identify the parameters of a site in itself, and more so in comparing the size of separate sites, due to differential sites types, preservation, sampling method, if the site has been totally excavated or surveyed, the obscuring of separate occupation phases etc. All such factors may contribute to less representative data that are used as a basis for palaeodemographic modelling. This is problematic as the clumping together of temporally distinct sites may appear contemporaneous and thus inflate the number of sites per period (if slotted into time series). "This problem results from the use of data in accumulated … In demographic terms, this distorts estimates of past populations by combining centuries or millennia into a single time phase" (French 2016:165). Schacht (1984) provided an early and important discussion of the prospects for reducing "contemporaneity problems" in archaeological population size estimates.

The proxy problem

All palaeodemography is based on proxies due to the lack of direct observation data on demographic variables. What is the correspondence between past population and population proxies? What level of precision may be achieved when applying one, or the combination of more proxies? Important discussion are to be found in (Chapman 1999; Crombé and Robinson 2014; Palmisano et al. 2017; Williams 2012).

4.3 Data presentation: The North Norwegian Radiocarbon Record (NNRR)

The initial idea of the *Stone Age Demographics* project in wanting to compile a radiocarbon record, was based on the exceptional characteristics making Arctic Norwegian data particularly suitable to radiocarbon-based palaeodemographic modeling. Before turning to some of the potential biasing factors, it is important to highlight the particular strengths of the NNRR dataset:

- The radiocarbon record uniformly stem from hunter-gatherer populations throughout the selected study period. This ensures seldom-met consistency in depositional practices and thus more directly comparable results than in areas influenced by major economic and adaptive shifts, e.g. the introduction of agriculture.
- The dates predominantly stem from HRM/rescue driven archaeology, subject to standard dating procedures and avoiding the major investigation bias of intensive investigations of particular cultural horizons. This produces highly consistent sampling. The HRM produced data are arguably less prone to such biases by force of responding to external economic drivers, covering all periods and areas with greater representativity than that of a research-driven database likely would have produced.
- A special characteristic of the NNRR and Arctic Norwegian Stone Age archaeology in general, is the magnitude of settlement housing features visible on the modern surface. Although this produces poor organic preservation in most cases, it also provides unmatched resolution, in the sense of being able to attribute dates to individual habitation features.

When counteracting the cons and combining the pros of this record, I would go so far as to claim that it presents an ideal case for the application of the SPD method. Given these strengths, a radiocarbon database was constructed for the purpose of the palaeodemographic analysis of prehistoric Arctic Norway through a review of available dates from multiple sources. The following procedure was established in order to collect the most complete database as possible (full description of data selection criteria and measures taken to vet the record can be found in (Jørgensen 2018)):

> **-** "Every radiocarbon date with a confirmable cultural origin within the timeframe of 11.500–1500 cal BP from Troms and Finnmark counties was compiled into the regional database. The termination date of 1500 cal BP is set some centuries after the partial introduction of agriculture and adoption of iron technology in northern Norway, in order to cover the entire period of Stone Age adaptations. This

ensures the highest possible continuity and comparability of data and takes into account the statistically unreliable edging-effects introduced by the applied methodology.

- The only cultural entity excluded from the database is hunting pits, as they produce contextually unreliable dates. Otherwise, every confirmable archaeological date was included, ranging from settlements and graves to ceramic residues.

- Data was collected by a thorough review of all published material, both in the academic literature and excavation reports.

- Unpublished dates were collected through personal communication with individual researchers and groups, as well as going through museum archives for unpublished and unfinished material.

- Data collected by the regional heritage authorities are also included, as they occasionally date samples collected during field surveys.

- A date lacking confirmable information on any variable resulted in exclusion; a total of 115 dates (9,54%) were omitted (see SI database)." (Jørgensen 2018:2).

The sample composition of the NNRR is presented in (Table 1), covering dates >1500 BP and older, from Troms and Finnmark Counties. The database exclusively contains samples of a secure cultural origin. There were 1205 dates in the original paper that have also formed the basis for the case studies, with a slight increase since then, to the current size of 1239 dates. Of these, approximately 800 dates (65%) stem from development-led excavations.

The samples are predominately made of charcoal. Common practice is to look for datable samples made of annual or multi-annual plants in the lower lifespan age range, such as seeds or nuts, or in the case of wood; small birch branches, in order to minimize the old wood-effect (Schiffer 1986). An unknown proportion of charcoal samples are made on long-lived wood species (conifers mostly), as most age determinations made prior to 2000 were not subjected to dendrotaxonomic identification. This introduces additional uncertainty. A small number of determinations made on burned bone as well as unburned bone of various species, some of which are marine, are also included. A selection of samples stem from ceramic crust residue as they mark important cultural transformations within the region. Both shell, marine fauna and ceramic residues are prone to marine reservoir offsets (Philippsen et al. 2010; Philippsen 2013). The rationale for inclusion is based on a review of samples exhibiting temporal correspondence with additional material inventory. The sample size of dates subject to the reservoir effect does not alter the probability distribution in any significant way. Dates suspected of being influenced by the marine reservoir effect have corrected using the Marine Intcal13 calibration function in Reimer et al. (2013), informed by local estimates of the effect (Mangerud and Gulliksen 1975).

The database also contains dates from several regions and periods that are not of relevance to the current thesis, and have therefore not been included here. This includes (n=87) dates from Stone Age sites in Nordland County. Although not systematically collected, these dates constitute the large majority of dates from Nordland within the time interval studied here as I got dates directly from the NTNU dating facility. Future efforts should expand on and complete this collection, particularly when considering the current large-scale excavations taking place along the Hålogaland road on the border between Troms and Nordland Counties.

Beyond dates that were lacking critical information or turned out to be erroneous, some other categories of dates were excluded. This included dates of strictly palaeoenvironmental origin although recovered from archaeological contexts. Although I retrieved archaeological dates directly from the radiocarbon dating lab at NTNU, some turned out to be of natural historical origin, rather than cultural: dated moraines and beach-ridges for shoreline displacement reconstruction.

The many dates (n=84) from the Kveøy Early Iron Age farm site excavation have been excluded. This was due to a combination of the dates stemming from the border of data catchment, representing a very distinct agricultural settlement and thus outside the primary scope of this thesis in investigating hunter-gatherer population dynamics. If included the dates would only greatly underline the already massive spike during the Early Iron Age.

Hunting pits were also excluded. As stated in the papers, this is due to their inherently unreliability in dating. It is not clear what event is targeted when dating hunting pits. While hunting pit dates could have been included, such has not been the case here. Others might have done otherwise, yet the rationale for excluding them is that they grossly misrepresent both the use of any individual hunting pit (due to unreliable dating and potentially very extensive re-use), but also contributing to a skewed representation of inland activity as they do not relate to occupational events – thereby being of less demographic interest. A problem further corroborated by the generally low radiocarbon sampling density of the interior. Recently, several hundreds of hunting pits have been discovered in the Arctic Norwegian interior, aided by LIDAR technology (Hood in press). This fact, combined with the difficulty with which to determine the age of such structures, suggest that the chronology and temporal dimension of the hunting pit system phenomena should benefit from more targeted investigations.

Table 1 Vital statistics of the NNRR dataset, reporting for Troms and Finnmark counties, >1500 BP.

Site and area breakdown	**Total**	**Coastal dates**	**Interior dates**	**Troms County**	**Finnmark County**	
Frequency	1239	1093	146	350	889	
% of total	100	88,22	11,78	28,25	71,75	
Material breakdown	**Charcoal**	**Ceramic residue**	**Burned bone**	**Marine shell**	**Antler, tooth, bone (unburned)**	**Charcoal of long-lived wood species (conifers)**
Frequency	1103	44	12	31	43	84
% of total	88,02	3,55	0,96	2,50	3,47	6,77
Municipality breakdown	**Frequency**	**% of total**		**Feature breakdown**	**Frequency**	**% of total**
Hammerfest	433	34,95		House pit	637	51,41
Tromsø	215	17,35		Activity area	393	31,72
Nesseby	111	8,96		Midden	82	6,62
Sør-Varanger	79	6,38		Grave	22	1,78
Porsanger	46	3,71		Coocking pit	18	1,45
Kautokeino	42	3,39		Field horizon	13	1,05
Harstad	38	3,07		Rock shelter/cave	12	0,97
Kvæfjord	33	2,66		Post hole	12	0,97
Måsøy	28	2,26		Tent circle	10	0,81
Gamvik	27	2,18		Pit	7	0,56
Karasjok	27	2,18		Farm mound	7	0,56
Vadsø	25	2,02		Bloomery	7	0,56
Alta	20	1,61		Slab-lined pit	6	0,48
Bardu	15	1,21		Rock art feature	3	0,24
Hasvik	12	0,97		Charcoal pile	3	0,24
Nordkapp	12	0,97		Cairn	3	0,24
Kvænangen	9	0,73		Cultic feature	2	0,16
Målselv	8	0,65		Kiln	1	0,08
Skånland	8	0,65		Stray find	1	0,08
Skjervøy	7	0,56				
Tana	7	0,56				
Berlevåg	5	0,40		**Excluded dates**		**Frequency**
Kvalsund	5	0,40		Exluded (erroneous, hunting pit, environmental)		121
Berg	4	0,32		Out of range (1500-150 BP)		376
Tranøy	4	0,32		Kveøy project		84
Kåfjord	3	0,24				
Vardø	3	0,24				
Bjarkøy	2	0,16				
Karlsøy	2	0,16				
Lebesby	2	0,16				
Båtsfjord	1	0,08				
Lavangen	1	0,08				
Lenvik	1	0,08				

4.4 Critical evaluation of the North Norwegian Radiocarbon Record (NNRR)

Above I presented a general review of critical factors in palaeodemographic modelling and commented upon some of the responses that have been pervasive in the recent literature. Here I turn to specific factors thought to shape the properties of the NNRR dataset – for better or worse. As taphonomic biases have been covered more thoroughly in the original publication (paper 1), and the difficulty with which further progress can be made in this domains, I here prioritize potential creation and sampling biases.

4.4.1 Creation bias

An important factor that can introduce skewed results in palaeodemographic modelling based on radiocarbon dates are variations in past deposition rates of the organic material that gets dated. Some attention has been devoted to this issue in the global literature (e.g. French and Collins 2015:128), yet a set of particular formation processes of Arctic Norwegian archaeology makes the class of creation biases particularly crucial to account for.

In fact, there are quite a number of misunderstandings and under-theorized conceptions of what SPDs actually do, particularly concerning the "more people, more datable stuff" theorem. The way I see it and try to develop in my work, is that in essence, this is actually an expression of deposition rates. This provides the opportunity to return to the study of formation processes. Deposition rates and -practices are possibly more tangible and familiar concepts to non-modelling archaeologists when grappling with what SPDs actually represent, as any past phenomenon has to deposit some material correlate for it to be susceptible to empirical investigation. The intensity of site use, length of occupation and population density/size are all interrelated variables, connected by fairly well-established mechanisms of how sedentism and mobility are traceable in the archaeological record by way of "distinct" depositional rates and practices. Site/population nucleation vs dispersal and their impact on site reuse is highly important in the local context of the NNRR – to which I devote most attention.

4.4.1.1 Reuse

A special characteristic of the NNRR and Arctic Norwegian Stone Age archaeology in general, is the magnitude of settlement housing features visible on the modern surface. More than 6000 house-pit features are currently registered in northern Norway (all of Nordland county included), when reviewing the cultural heritage database (https://askeladden.ra.no). Although huge, this is a drastic underestimation of the actual number given multiple shortcomings of this dataset. The rather extraordinary number of known sites and dwelling features is the result of minimal soil accumulation in the Subarctic, coastal environment, providing high archaeological visibility of sites dating throughout the Holocene. The majority of radiocarbon dates in the NNRR database are derived from dwelling features – that is, the remnant foundation of semi-subterranean dwellings. Although this provides unprecedented contextual control of the dates, repeated occupation of house features – so-called "reuse" - in which deposited organic material from distinct events are either mixed or not represented by radiocarbon dates, constitute a major problem we cannot properly account for or control in palaeodemographic modelling.

Dating protocols in the area have tended to emphasize the best/most obvious context, aiming to establish the date of house construction or providing an associated date for the inventory, often at the expense of secondary occupational events. The implication is that sparsely dated features most likely underrepresent multiple occupations. The "*Stone Age Demographics*" project has made an effort to determine the extent of this problem by re-dating samples from old excavations and performing new excavations with high-density, high-resolution dating protocols. Previously collected, yet undated samples from Stone Age dwellings, frequently produce evidence of reuse into the Early Metal Age and Iron Age. In particular, a fellow PhD (Kenneth W. B. Vollan) has been employed in the "*Stone Age Demographics*" project with the intention of disentangling some of the longstanding issues facing the resolution of the occupational histories of Stone Age houses and sites in Arctic Norway. As I was tasked with top-down macro scaled problems, he is tasked with bottom-up micro scaled problems. He therefore provides important ground-level demographic data that ideally would be integrated with my own work. The logistics of our projects, e.g. my project starting considerably earlier than his, has not allowed for extensive integration within the timeframe of my employment, although see (Damm et al. 2019). However, I here recapitulate relevant findings of his, providing some tentative integration.

Through extensive re-dating and Bayesian analysis of previously excavated sites, Vollan´s results demonstrate that in cases of well-preserved habitation stratigraphy, the number of identified occupational events is somewhat proportional to the number of dates extracted from a house feature, averaging at 2-3 events. In most ideal cases, excavations targeting house-pits with particularly favorable preservation and extensive dating protocols, possibly as many as 6 habitation episodes have been identified (Vollan in press:14; Skandfer and Vollan in prep). That house features are reused is no surprise. Inter-generational reuse and continuously maintained houses are well-known both in the ethnographic and archaeological record. Such practices commonly appear alongside increased sedentism, locational investments, and land-claims. However that the time separating occupational events often is in the range of multi-centennial to the millennial scale (Vollan in press:15), is somewhat surprising. Diverging absolute and relative typological dates of assemblages are frequently observed in dwellings, and have previously been recognized as indicators of reuse with potentially significant (millennial scale) intervals (e.g. Andreassen 2001:52). Yet, given the low chronological/typological resolution of most lithic industries in the area, more precise (centennial scale) pinpointing has not been possible. Lack of abundant and consistent dating protocols has also undercut the prospect of determining whether such secondarily deposited assemblages were formed in house features or dumped secondarily as part of a waste management policy taking advantage of house depressions as garbage traps.

Even though reuse appears more pervasive than previously thought, Vollan highlights that singular occupational histories are common (30 out of 51 dwelling plots = 59%). This is also the case among houses that are well dated, implying that this is not an effect of investigation biases (Vollan in press:12). Reuse, therefore, does not present a uniform phenomena. Site geography and attractiveness has been pointed to as confounding factors potentially driving the dynamics of reuse (Vollan in press:15). Houses/sites occupying attractive plots that are environmentally and isostatically stable for extended periods and/or hold important strategic or logistical positions are more prone to reuse (Wren et al. 2018). However, the geography of the site, in terms of size and physical properties, also impact reuse practices. Spatially small and crammed sites leaving little room for expansion or breaking new ground should exhibit significantly more reuse compared to geomorphically favorable and open-ended sites.

In the more general sense, there are other factors that increase and decrease the likelihood of house and site reuse. In favor of reuse, there is the purely physical advantage of rebuilding on an already established plot, as laborious pit-digging is reduced from previous occupations (Hertell and Manninen 2006). Affirming continuity and ownership of a site may also drive the regularity of reuse (Hood, Helskog, et al. in press; Skandfer 2012). The permanence of material structures, alongside increasing investment in stationary facilities, have frequently been pointed to in this respect (Smith and McNees 1999). Going against reuse are social institutions and norms prohibiting reoccupation of houses or sites for a number of different reasons The ethnographic record contains frequent examples, such as taboos, territoriality, rotating land-use patterns etc. One ethnohistoric example of this are the distinct social norms regulating rights of reusing other family groups´ sites in Inuit western Greenland, that were particular to inland contra coastal sites (Knudsen 2007:60). Although part of the particulars of how history unfolds, such factors carry little explanatory weight outside the realm of optimum-resolution, historical cases, and thus are not very helpful in developing deep-time perspectives. Then what are the (potential) aggregate effects of reuse on SPDs in the area?

Vollan identifies what appears to be distinct intervals of lesser reuse of older house features in three periods: 5400-5000, 3800-3500 and 3000-2500 cal BP (Vollan in press:16). All correspond to population troughs in the regional palaeodemographic model (see paper 1). The reader must be aware of potential circularity here, as both SPD and Bayesian analyses rely on the same data (radiocarbon dates), although differently construed, binned and analyzed. It is not clear whether this correspondence should be taken as providing mutual support for both analyses, or be dismissed as circularity. At this point we cannot do more than provide tentative suggestions. It is my belief that the correspondence between overall population trend and micro-level site activity is exactly what would be predicted of a causal relation.

If we accept the idea that the demographic trends are mostly correct, a further supporting factor of the correlation between reuse and population density is to be found in the theoretical predictions of the Ideal Free Distribution (IFD) model (Fretwell 1969). The IFD model states that increased absolute population numbers would result in increased packing when all high-ranking sites on the landscape were filled. As population packing increases in tandem with sedentism, this drives the need to more frequently reuse previously inhabited dwelling plots. The social aspects of “place-making” are also expected to be positively correlated with increased packing and sedentism, corroborating the likelihood of reusing plots. In contrast, decreased population numbers result in a reduction in the number of settlement locations on the landscape, with only the most optimal locations still being used. Abandonment results in no re-use of marginal settlements, while the most optimal locations might be re-used. As there is a plausible theoretical mechanism consistent with the observable results, I am inclined to accept them. This should be explored in much closer detail in future research, although this would require high-cost investments in large-scale excavations and extensive dating protocols. Thus we will not advance knowledge on this matter for some time, as it requires accumulating more, and reliably representative, data.

The formation processes of reuse are important to consider. The stratigraphical law of superposition states that more recent deposits (e.g. from reuse) will superimpose that of older strata (e.g. older habitation phases). However, reuse of houses often clear out/dig through original house floors and discard what material might have contributed to a more representative dating protocol. Thus, reuse may be as much a problem in obliterating older habitation phases. This is all the more likely considering the dominant dating strategy in the area has been to target hearths. Hearths are often the only context with sufficiently preserved amounts of charcoal for dating (at least used to be prior to

AMS dating). Yet the dating potential of hearths is arguably prone to destruction by later reuse/reconstruction. Examples of multi-layered hearths and distinct house floors with separate hearths do occur (e.g. Simonsen 1961:346), yet is far from being the norm.

A highly complex stratigraphical intermixing can result from reuse, producing discontinuous, chaotic and even reversed sequences. However, the pedological and geomorphic conditions at most sites in Artic Norway are virtually without stratigraphy and produce “flat” palimpsests. Consequently, the principles of preservation and taphonomy may speak in favor of the presented results. In palimpsest contexts this becomes an important factor as degenerative factors, e.g. physical and chemical weathering, make it more likely that younger deposits are preserved and present more organics suitable for dating, thus being overrepresented at an exponential rate, compared to earlier sites/deposits (Surovell et al. 2009; see also Brantingham et al. 2007).

The number of inhabitants per dwelling feature may also influence the demographic modelling. Although mainly an issue if attempting to construct absolute population estimates, it can be an issue of relevance here if the number of inhabitants per house (and the associated depositional character) greatly varied through time, thus shifting the sampling probability of particular sites. That is, the social and organizational structure of the population may influence the results by changing deposition rates, on par with the effects of changing settlement nucleation vs dispersal. Intuitively, housing practices where one family occupies one house might produce a much larger sample of houses compared to a housing practice of multiple families occupying a single house, total population held constant. Yet this may be fallacious thinking, as it is just a reflection of the impacts of changing mobility on depositional rates. If extended families lived in few houses, the archaeological imprint would be much more significant than if spread thin on the landscape by small groups occupying numerous houses. We cannot control for this factor, but in the end, it may be evened out by taphonomic processes making it more likely that sites used intensively by larger groups over extended periods survive into present representation better than a plethora of ephemeral sites inhabited by fewer people.

Counting of habitation structures on the basis of extensive field surveying and ascribing age through shoreline displacement models in an area with more pronounced and continuous isostatic uplift would provide a demographic proxy independent of the radiocarbon record and should prove useful in qualifying the modelling results. This has been done on the Finnish coast, where the results are consistent with that of the radiocarbon-based population model (Tallavaara and Pesonen 2018). Preliminary results of correlating the SPD population model of the western coast with the temporal frequency distribution (TFD) of dwellings at Sørøya island (also western coast), suggest coincidental trends (Fig. 8) (Damm et al. 2018). The temporal resolution of the dwelling TFD is crude, based as it is on a combination of shoreline-dating, evaluation of local topography, and dwelling shape typology. It is also troubled by the limited isostatic uplift and partial transgression effect in the area. Yet when considering the degree of overlap at this stage, I believe this corroborates the SPD results.

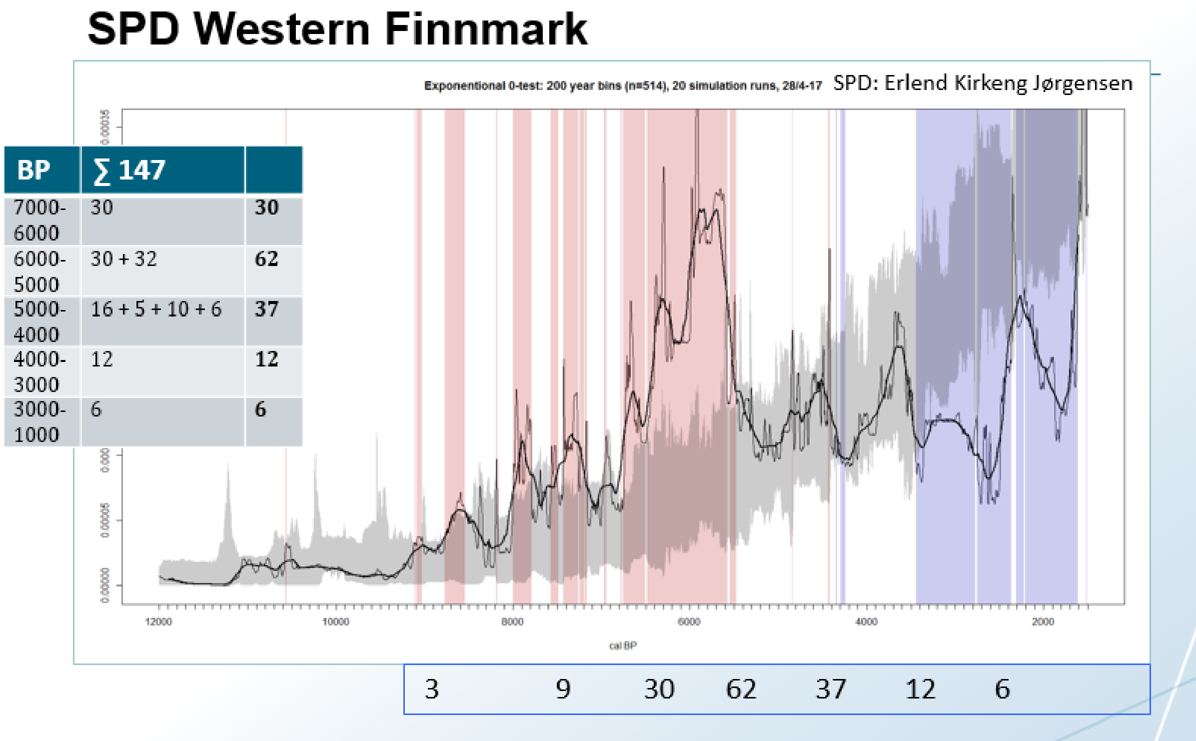

Figure 7 SPD compared to time-bracketed house counts on the NW coast of Arctic Norway. Reproduced with permission from (Damm et al. 2018).

In the end, it is important to understand that although there are innumerable factors that might somehow skew the representation of a single house or site in the radiocarbon record, the SPD methodology is founded on the premise that shortcomings of particular dates are evened out when amassed into big datasets, sensu the Law of Large Numbers (Timpson et al. 2015:201). This is the foundational idea of quantitative science. In the particular context of the NNRR dataset, it must be stressed that the local archaeological record is the result of seldom-matched consistency in depositional character. Major economic and adaptive shifts may arguably reduce the homogeneity of the radiocarbon record through drastic changes to depositional practices, by way of settlement and mobility regime-shifts. This is a concern in demographic models of areas greatly impacted by the introduction of agriculture. The prehistory of Arctic Norway, however, did not feel the influence of agriculture to any extend within the timeframe represented in the data collection interval. To the contrary, the area exhibits continuous foraging populations even into the present, and is situated well above the limit of agricultural economies. As the Neolithic never happened here, there has not been the intense focus on the Mesolithic/Neolithic-transitional boundary, which present an obvious hurdle to reliable sampling frequently found in continental European archaeology. This means that even though recurrent reuse practices may not be properly controlled for in the NNRR database, the *magnitude/amplitude* of the settlement and adaptive changes are significantly less compared to that of most other radiocarbon datasets.

4.4.2 Sampling bias

As in all domains of archaeological data catchment, palaeodemographic modelling is subject to a host of sampling biases. In fact, being essentially a big data-analysis of existing data, all prior sampling biases of underlying datasets are implicated in this form of analysis. This has created the need to perform qualitative culling of individual radiocarbon dataset, the procedure of which is presented in the original publication for every ^{14}C dataset.

That being said, no formal analysis of how sampling biases impact SPD results have been published so far. As such, there has been very little debate over this at the conceptual level. However, ongoing simulation studies suggest that larger sites/residential stability end up being overrepresented due to sampling biases (E. Crema, personal communication, 21.1.2020). This is in line with established archaeological intuitions as well as firmer empirical studies confirming that preservation of organic materials depend on the scale/intensity of deposition.

Although sampling biases are covered to some extent in the original publication (paper 1), I here go into more detail on aspects of sampling practices. I will be concerned with what I view as the four most prominent factors potentially introducing sampling bias into the NNRR: 1) dating protocols 2) research agendas prioritizing middens sites in eastern Finnmark, 3) the priority of coastal over inland sites following HRM practices, and 4) the general priority of visible dwellings over open-air sites.

4.4.2.1 Dating protocols

Radiocarbon dating in Norway was subject to particular regulations up until the late 90s that require some explanation as they influenced dating protocols and thus the accumulation and sampling of radiocarbon dates on which this thesis is built. Prior to 2000, the vast majority of radiocarbon determinations of Arctic Norwegian archaeological material was conducted at the national radiocarbon laboratory at NTNU, the Norwegian University of Science and Technology in Trondheim. This provided a high level of sample consistency and control of the data employed in the presented SPDs. I retrieved all their archived data originating from the defined study area and was able to crosscheck with the existing dataset, correct errors and add extra material. The NTNU lab was subsidized by state funds through the Research Council of Norway, and researchers had to apply to get samples dated. It became common practice that only two dates per site/feature were permitted. This was due to the limited capacity of the facility, as well as the funding situation. In practice, this meant that the priorities made by the application board became decisive in the evolution of dating protocols in Arctic Norwegian archaeology.

Although researchers were free to buy commercial dating services beyond what the NTNU lab provided, this rarely happened due to the high cost of radiocarbon dating at the time. Researchers within Norway also got a reduced price at the subsidized NTNU lab, which kept most archaeologists loyal to the national dating service. What suffered from this arrangement were sites of particularly high dating potential. The practice of only dating prominent features, such as hearths and the main living floor of houses, should possibly be viewed as a risk-reduction strategy under this dating regime where researchers had to make every age determination count. Secondary deposits, less prominent features, typologically ambiguous localities, etc. would not be prioritized under such conditions. The end result is that of a potential sampling bias underrepresenting the frequency of reuse and perhaps certain time periods. Another implication is that fine-grained stratigraphical sequences (whenever encountered) that could throw light on the pressing issues of site longevity and reuse, were not systematically dated. The fairly recently excavated Bergeby site provides a telling example, as the investigator prioritized her limited dating opportunities on the house feature, with only one date representing what was a thick midden containing a large archaeofaunal sample and well-preserved osseous material (Schanche 1994:31).

4.4.2.2 Midden sites

As noted above, it might be suggested that preservation of organic materials depends on the scale and intensity of deposition. A local example of this density-dependent preservation are the shell middens in Varangerfjord representing increased residential stability resulting in increased deposition rates that produce favorable conditions for organic preservation due to the basic chemistry put in place by decomposing shells, rich in calcium-carbonate (Hood and Helama 2010; Hood and Melsæther 2016).

Shell midden sites have been the object of particular research focus. The prospects of stratigraphy and organic preservation make such sites attractive objects for study in an area generally lacking both. Combined with the fact that shell middens contribute to the visibility of a site in the landscape, it seems plausible that such sites might be overrepresented in the radiocarbon record. There is just considerably more to date at these sites than most others. Most shell middens belong to the Gressbakken phase, which constitute a significant peak in the regional SPD (Jørgensen 2018), reviewed in detailed in (Jørgensen and Riede 2019). As such sites are particular to the eastern coast, one might expect this uneven geographical distribution to introduce a stronger bias there than on the western coast. When comparing the regional population models (Paper 1), the Gressbakken phase population cycle (4200-3800 cal BP) is very pronounced on the eastern coast. This could go some way in supporting a biased representation (sampling and taphonomic biases). Rather to the contrary, the majority of dates making up the Gressbakken population cycle do not stem from middens but from dwelling features, mainly hearths. What is more, assuming a biased representation due to the priority of midden sites is jumping the gun without considering why midden sites are only present in Eastern Finnmark.

It has been proposed that the different climatic conditions between the east and west coast is to blame, particularly the double amount of precipitation in the west which contribute to dissolving the calcium carbonate of shell middens (Hood and Melsæther 2016:5). This, however, does not account for the great local variation of the topographically complex western coast. Inner fjord areas on the west coast receive equal amount of precipitation as the east coast, yet no shell middens have been reported. Although this is usually where the story ends, it is not the complete picture. Shell middens/layers have in fact been excavated on the western coast of Nordland county, at a couple of often overlooked sites, such as the Kirkhellaren cave (Gjessing 1943) and the Storbåthellaren cave (Utne 1973). These sites demonstrate that shell exploitation was practiced on the west coast and underline the bewildering distribution of midden sites. There is also the Nordland1 site at Værøy Island, which contained a considerable deposit of preserved faunal remains (Ts8126-7, Helskog, unpublished). Yet given the lacking documentation of the site, it is not known whether it was part of a de facto shell midden.

Concerning the potential biasing impact of midden sites on the demographic models, shell midden sites do not dominate the radiocarbon record to the extent one might expect. Most of these sites were excavated prior to or during the infancy of radiocarbon dating. At the time, radiometric dating was costly, thereby limiting the number of dates for financial reasons. Dating protocols fully exploiting the stratigraphic build-up of shell middens have only been applied in three recent cases (Hood and Helama 2010; Hood and Melsæther 2016; Martens et al. 2017). The minimal number of high-density dating attempts, combined with the binning procedure of SPDs, ensures that midden sites are not drastically overrepresented.

Taking all the above idiosyncratic factors and contingencies into account, I believe that the bias of the larger, more visible and often better preserved midden sites is not particularly strong. It seems to have been balanced out by most excavations taking place either prior to the advent of radiocarbon dating or limited by existing dating protocols. Counterintuitively, this dating practice runs the risk of underrepresenting larger sites in particular, as a larger proportion of houses would have been dated at small sites compared to larger sites.

4.4.2.3 Coastal over inland sites following HRM practices

The archaeological record of Arctic Norway, and consequently the NNRR, is subject to a skewed spatial sampling. The main focus has been directed at coastal sites, resulting in a radiocarbon record less representative of the interior. This is a natural consequence of significantly higher developmental rate per square unit on the coast than inland. As archaeological excavations in Norway are almost exclusively rescue-driven, this skewing is not a consequence of incommensurate research strategies, but more due to economic activities and population centers being located along the coast, thus increasing the pressure on coastal heritage sites during development. The lower visibility of inland sites further contributes to their potential underrepresentation in the radiocarbon record. This is both due to the more ephemeral character of most inland sites, leaving less of an imprint on the landscape, as well as being obscured by more active peat/soil formation and sand drift. This problem has been acknowledged for quite some time, with Skandfer (2003:53) summarizing related and other potential causes of this skewedness). When summarizing the results of large-scale surveying in northern Troms in the mid-80s, it was stated that current survey data was coastally biased:

> *"The economic limitations, combined with the aim to locate as many sites as possible, has led to a consentration [sic] of the Survey to the inhabited narrow coastal zone and, within this zone, to sites with visible surface structures. The limitations in the current archaeological knowledge are also strongly felt within our region where a large part of the sites belong to site categories which have been subjected to little research interest in the past"* (Holm-Olsen 1986:82).

Moving on almost three decades, the majority of the interior has still never been surveyed, presenting an obvious sampling bias. Recently, extensive efforts have been made by the project "*Landscapes and Resource Management in Interior North Norway*" at UiT in targeting previously unexplored inland areas (Skandfer et al. in press). Still there are major representativity problems: most of the work has been done in the river valleys, little on the interfluvial plateau in Finnmark.

However, there might also be particular behavioral drivers in the past that contribute to the lower amplitude of the interior archaeological signal. One can easily envision at least three scenarios contributing to this picture: 1) lower population densities in the interior throughout the Holocene, 2) highly variable, sporadic yet occasionally intensified interior habitation, 3) different mobility and settlement patterns in the interior compared to the coast not properly picked up by current sampling.

There has been a long tradition of assuming separate coast and inland populations in the LSA, with particular emphasis on the rock art sites acting as nodal points in the nucleation phase of a fission/fusion mobility pattern [accounted for in section 2.1]. Coastal/inland dynamics have been given some attention in this project as well, as viewed through the lens of population ecology. Such dynamics were modelled and discussed in paper 2 (Jørgensen and Riede 2019). The results suggest extensive population packing at the coast in concert with an apparent de-population of the interior during the 6000 cal BP demographic cycle. What is more, the archaeological materials and the radiocarbon record of the interior suggest varying intensities of inland use over time, with two periods of apparently low activity that are synchronous with major activity on the coast (6500-5000 and 2000-1000 cal BP) (Hood, Blankholm, et al. in press). Thus, the previous mantra of distinct populations interacting at particular nodal points in the landscape during the mid-Holocene, seems less plausible when considering these results. The patterns are more in line with dynamic and adaptive responses to the governing environmental conditions, in which the most productive period on the coast facilitated a more complete adaptive niche - potentially attracting people that may previously have relied more extensively on terrestrial resources.

This does not exclude the possibility that particular inland sites were intensively used throughout extended periods of time. Indeed, some larger houses have been uncovered in the interior, such as the infamous Noatun sites (Simonsen 1963). Other dwelling features in the interior have also been investigated recently, yet display a lower intensity of use than that on the coast (Skandfer and Hood in press, in press b). However, the biogeographical distribution of important terrestrial resources (e.g. ungulates) likely produces a very different human mobility pattern and economic strategy inland than on the coast. Intense reuse and nucleation of sites can occur among even the most mobile of people when critical resources have a very limited geographical distribution through time. This is known as "tethered nomadism" (Taylor 1964). I believe we witness a variation of this mechanism in play in the local area, in which the mobility pattern may have been tethered to sites positioned at strategic stretches of the Alta/Kautokeino canyon river (Fig.9). Multiple sites were excavated prior to the construction of a hydroelectric dam and subsequent submerging. The results indicated intense reuse of hunting and processing sites, with minimal indications of habitation beyond short term-occupation (cf. Hood and Olsen 1988). Particularly the Čávžu site is strategically positioned to take advantage of both riverine resources in the canyon and ungulate hunting at the mountain plateau. The material evidence from these sites correspond to the predicted character of tethered nomadism. This is in line with the assumed lower population densities in the interior expected to be of a more sporadic character compared to the coast – a response to the stronger seasonal variation in environmental productivity and greater need for risk reduction measures in the interior.

Another critical factor in discussing the representativity of the interior, as presented in the NNRR, is the issue of pit-fall hunting traps. Massive pit-fall systems are distributed across the northern Fennoscandian interior and constitute what appears to be an economic strategy unique to this region. They testify to extensive resource exploitation in the interior, and may give the impression of being at odds with the perception of limited inland activity in certain periods. This seems a reasonable objection considering the high investments going into the physical construction and social organization of managing/operating these facilities, that may number in the hundreds. Despite their frequency, dates derived from pit-fall traps have been excluded from the NNRR. Such features are therefore not represented in the SPDs. They were omitted for a number of reasons, first and foremostly in that they do not represent habitation features – that is, not directly related to human demography. In addition, pit-fall features are notoriously difficult to date, never knowing what the associated date represents. The multifaceted dating problem of pit-falls (both the context of dates, how many pits in a single system are contemporaneous, and how many systems are contemporaneous) has been discussed in (Hood In press b).

Figure 8 The Alta/Kautokeino canyon river prior to damming. Photo: Knut Wilhelsen/NVE, 1979.

It is not possible to firmly establish the representativity of the inland record at this point. However, the inverse trends of coastal versus inland population models might indicate that the interior record really do convey meaningful information. The mostly ephemeral character of the interior archaeological record is also in line with IFD-derived expectations; as the prioritizing of the ecologically most productive patches would in the local case result in the priority of the coastal biome.

Note that the loss of coastal sites is likely drastically higher than that of inland sites - a factor that is often overlooked when discussing representativity. The coast has been more densely settled throughout the entire Holocene. Both historic and recent urbanization and the ever-expanding impacts of infrastructure on the landscape, has been disproportionally coastal. The rugged terrain of the northern Norwegian coast results in reuse of what little (flat) space there is, as has always been the case. Even if we discount the impact of urban centers on the representativity of the archaeological record in the area, roads have been strategically placed atop the Tapes transgression beach ridge, which is the most densely settled natural feature in all of northern Norway throughout the Stone Age. Beach ridges provide a flat surface and natural drainage in an otherwise steep terrain. They have therefore been a favored target for road construction long before modern archaeology entered the game. Most of my 60 km commute to work consist in driving on top such a beach ridge. Almost no sites are known from this coastal stretch, which is a daily reminder of the large-scale obliteration of archaeological data on the coast, a fact recently corroborated by large-scale surveying comparing the density of sites on coastal and palaeo beach ridges removed from coastal proximity by isostatic uplift (Melsæther 2016:225).

4.4.2.4 Dwelling sites over open air sites

As previously noted, NNRR is particularly fortunate as to the high number of dates stemming from distinct habitation features, a consequence of the high visibility of coastal house-pit sites. A potential downside of this is the low representation of less obvious sites. Most focus has been directed at nucleated dwelling sites, much less on campsites and other “off-site” archaeological remains, as termed by Foley (1981). The potential biasing factor associated with this focus, is not being able to properly represent sites of a particular seasonal or functional character. More dramatically, this may impact the demographic modelling if the settlement pattern and residential mobility of the population varied markedly through time.

One of my major concerns in this respect is that of a potential underrepresentation of the early Holocene record. There is generally poor representation of the earliest period of northern Norway´s prehistory in the radiocarbon record. This likely stems from differences in settlement pattern and the lack of permanent structures drawing less attention. Taphonomic factors also take effect, as datable organics very rarely are preserved from the early Holocene archaeological record. ESA sites are mostly elevated above the reach of transgression and modern settlement disturbances, thus better preserved and represented than sites from the ESA/YSA transition. However, this trend is not properly represented by the NNRR. This is worrisome as initial ESA archaeology has received a fair amount of attention and many sites are known (Blankholm 2018a; Hood 2012), yet is nearly absent in the NNRR. Targeted surveying has been successful in identifying large numbers of sites (Gjerde and Skandfer 2018; Grydeland 2000; Kleppe 2014; Sandmo 1986), the majority of which lack dating potential and thus are not represented in the NNRR.

Recent HRM excavations have been successful in greatly improving the coverage of late ESA archaeology. But the way this success has come about provides some critical food for thought. A clear example is the way the Tønsnes site excavations contributed a large number of dates from an otherwise marginally represented period (8000-9000 cal BP) (Gjerde and Hole 2013). This was the result of large-scale soil stripping, which turned up multiple pithouses that were obscured by a thick layer of peat. Here, the investigators were successful in dating multiple features. Yet the conditions of which these sites were found, suggest a negative bias in over-representing sites visible on the surface.

Soil accumulation and reduced archaeological visibility is an increasing problem the further south you go along the Arctic Norwegian coast (Fig.10), a topic occasionally touched upon (Davidsen 2006; Holm-Olsen 1986; Thuestad 2014; Myrvoll and Holm-Olsen 2010). The Gisundet sound of inner Senja, as well as the Tjeldsundet sound separating Harstad/Narvik from Lofoten/Vesterålen are both regions that barely are represented in the Stone Age archaeological record, despite being prime coastal biomes. This lack is likely due to soil accumulation rendering them invisible, in addition to site loss following modern settlement and agriculture. The earliest archaeology of these areas is likely obscured or lost, and not represented in the NNRR. Indeed, recent HRM surveying have identified large and numerous settlements in the Tjeldsund region, at a surprising scale. Surprising to most of us, both in the sense that the topography was not expected to host such large nucleated sites, but also that the majority of surveyed sites are of early Holocene origin (Hole et al. 2016:209; Melsæther 2016:225). These findings are important to correcting the current representation, as the eustatic dynamics of the Lofoten/Vesterålen region and ensuing inundation of the majority of the Stone Age coast has left an impoverished record of the early periods – see discussion in (Davidsen 2006:96). These factors are all the more troubling as one moves into central and southern Nordland County which, in addition, is almost completely lacking systematic surveys of Stone Age sites, something we are in desperate need of remedying.

Figure 9 The impacts of increased vegetation coverage, soil accumulation and modern farming on archaeological sites become more strongly felt in the southern parts of the study area. A) Two Stone Age house depressions have been obscured by multiple silage bales. Sortland municipality, Nordland County. Reproduced with permission from (Thuestad 2013:10). B) Drone photo of exposed Stone Age dwelling features situated on top of the Tapes beach ridge. Store Sandvika site, Sørøya Island, Finnmark County. Photo: author.

By now the picture seems pretty bleak, and all of the biasing factors discussed so far I believe this is of the more important ones. That being said, one would not expect the ESA population to be of a comparable magnitude as that of the LSA. The pioneering population was initially very small and highly susceptible to fatal collapses, likely instigating repeated more or less successful pioneering attempts. Although the deglaciated coast would provide great economic opportunities, the terrestrial ecosystems did not settle into highly productive regimes for quite some time. Thus, it is reasonable to expect increased human growth potential in accordance with the ecological succession processes.

4.5 Result reliability: Binning and kernel density distribution

What is the status of the palaeodemographic modelling results presented in the papers when considering the above biases? I have tried to give a thorough account of the strengths and weaknesses of the NNRR for modelling purposes, but beyond such a qualitative review, there is no way of knowing fully the truth-value of the modelled results. However, there are ways of counteracting some of the biasing effects and thereby increasing the likelihood of tracking true demographic trends.

Binning procedures are important in this regard, by correcting biases in the underlying radiocarbon dataset employed in SPD modelling. The binning protocol employed in my work has been presented in detail in paper 1 (Jørgensen 2018:5). To recap, the now common protocol is to bin dates within 200 uncalibrated year intervals per site. This is in order to normalize the unequal dating density of individual sites, making sure that sites with high-density dating protocols do not contribute a disproportionally strong single in the SPD. However, this procedure is not universally applicable, as the effect of binning depends on the standard deviation of the dataset. The average standard deviation (ΔT) of a set of radiocarbon dates determines what is the necessary sample size for the SPD method to yield valid and reliable results. Through simulation, Michczynska and Pazdur (2004) found that a $\Delta T = 115$ years requires a minimum sample size of 200 dates for a 14 KYA time span, and 780 dates to produce robust results. At the time of writing (21.1.2020) the average laboratory error of the NNRR is ($\Delta T = 62{,}45$ years), calculated from the 1240 dates older than 1500 cal BP, from Troms and Finnmark counties. Considering that the NNRR dataset covers a 10.000 timespan, this is excellent resolution.

The SPD method was a great improvement compared to the initial use of dates as data that plotted dates as histograms (see; Haynes 1969; Holdaway and Porch 1995; Kirch 1980). The benefit of SPDs lies in having been demonstrated to require smaller data samples compared to histograms – respectively 759 dates for SPD and 1530 dates for histograms to achieve the same level of resolution and reliable results with a mean deviation of 115 years in the range of 0-14 kyr BP (Michczynska and Pazdur 2007:743). Thus, histogram time-series analysis is revealed to be a crude technique, requiring an approximate doubling of the dataset. The reason for this disparity stems from the histograms inherent need for compartmentalized categories with definite demarcations. SPD´s on the other hand are continuous probability distributions.

As previously stated, a particular strength of the NNRR is that a large majority of the archaeological record is relatable to and derives from individual house features - and recorded as such. I therefore decided early on to apply feature-level binning to the radiocarbon modelling as well, for several reasons discussed in paper 1. I did not want to conflate the existing resolution by binning at the site-level, as this site-level binning is a response to insufficient resolution in the first place. In support of this approach Enrico Crema responded that "the common binning approach applied to the level of site completely replaces this by effectively making the SPD a proxy of settlement counts rather than population size - the two are of course correlated but nucleation/dispersal would throw a curve ball" (E. Crema, personal communication, 21.1.2020).

Kernel density distributions (KDD) may be used as an indicator of the reliability of the SPD results. This is separate from the statistical envelope method, which is the dominant format of presenting SPDs, whereby fluctuations beyond the simulated envelope interval are rendered statistically significant, while fluctuations within the envelope are not significant. The KDD is handy in displaying the impact of binning on the modelled results. Figure 11 plots the kernel density distribution of the dataset, and shows the frequency of median dates stacked into five binning intervals [100, 200, 300, 400, 500]. The most pronounced fluctuations are more likely to persist across increasingly broad binning intervals. As shown by the plot, three peaks are distinguishable at every age bracket, including the 500 year interval. The smaller fluctuations visible, e.g. at the 100 year interval level, are more likely to be artificial fluctuations introduced by calibration for instance. The results of the KDD are in line with that of the statistical envelope simulation, implying robustness. The consistency of the pattern has been an important reason why my middle-range case studies have centered on these specific demographic events. Although I originally experimented with various binning sizes other than the most commonly used (200 year bins), there is no point in reducing the bin size to say 50 or 100 years, when the mean error of dataset exceed these binning intervals (±62.45 = 124,9 yr). Anyway, the point of SPDs is to provide long-term trends. It should be the ambition to greatly improve the resolution of the method, but currently, reducing the bin size does little more than introducing high-frequency, low-amplitude oscillations that are not statistically significant and mostly disregarded either way.

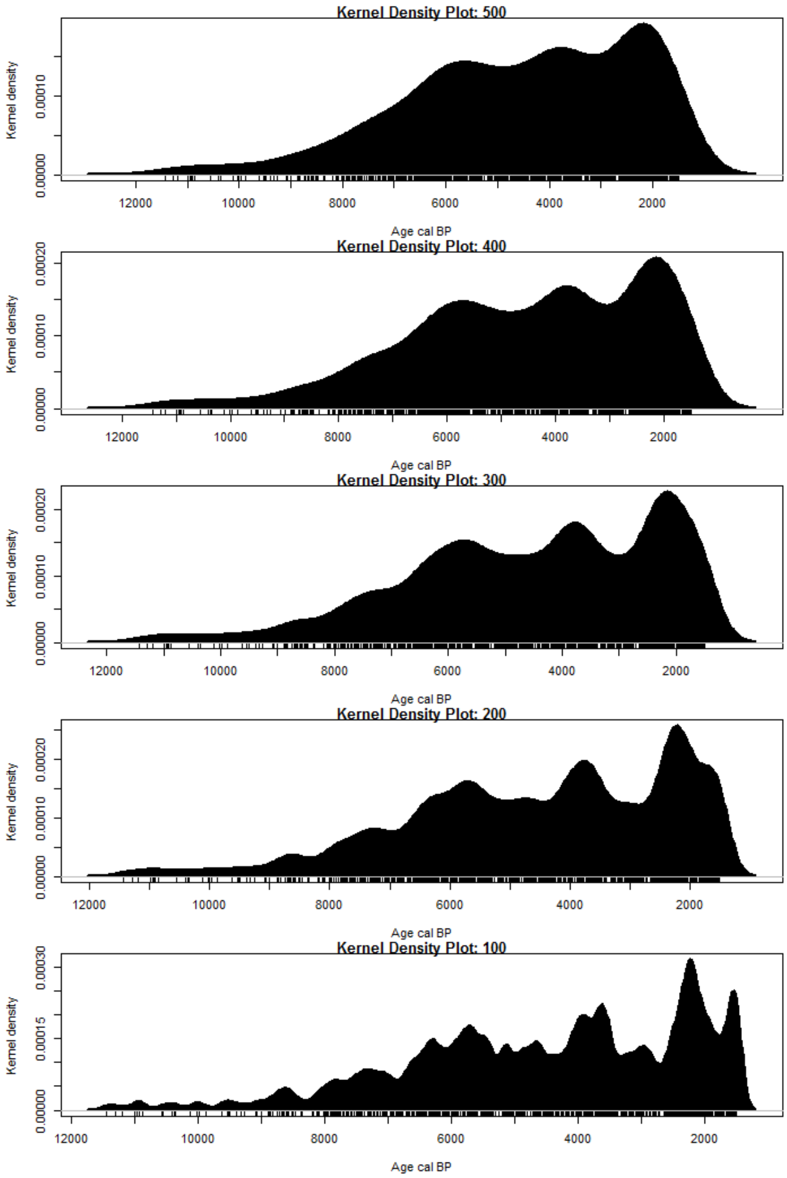

Figure 10 Kernel density distribution of calibrated median dates in the NNRR dataset.

So when do SPD oscillations carry meaningful information of actual demographic processes? There is no established protocol for this, beyond the strict cut-off line according to statistical envelope simulations. However, one frequently observes scholars discussing SPD oscillations regardless of their statistical significance – myself included. This might seem like poor scientific practice to outsiders, yet results from the insufficiency of only commenting on fluctuations that penetrate the envelope barrier (cf. Fig.8) when what we are interested in are the long-term trends. Disregarding the overall character of the trend on grounds of lacking statistical significance (if inside the statistical envelope) undercuts the very purpose of the exercise. The statistical envelope is premised on either exponential or static growth assumptions, and should therefore only be used as a reference in interpreting results, not as an absolute statistical test.

In line with this, the degree to which SPDs track actual demographic processes, as they are reflected in ethnographic and historic demographic/census data, has sparked a separate debate. There has been an interest in estimating population growth rates from the long-term trends of SPDs (Bettinger 2016; Brown 2017; Kelly et al. 2013; Zahid et al. 2016). However, the accuracy of such estimation is problematic due to the inherent smoothing and low temporal resolution of SPDs. This has been tested in an upcoming paper (Tallavaara and Jørgensen in press), by generating population growth rates from annual-scale ethno-demographic data and comparing them to growth rates estimated from simulated SPDs. The results demonstrate that SPDs are very bad at picking up realistic demographic patterns as they play out on a year-to-year basis – "realistic" in the sense of temporal resolution and demographic magnitude of actual demographic dynamics and the magnitude of fluctuations at the intra-generational scale. Instead, what SPDs track with high precision is long-term carrying-capacity at the population level and over significant time periods. This is demonstrated by simulated SPDs generated from randomly sampled radiocarbon dates (mimicking archaeological sampling) and set to track expected population dynamics under various productivity regimes. The long-term growth rate estimated from fluctuations in SPDs thus express the mean carrying capacity within the calculated time interval, which is a very different measure than actual, demographic growth rates. Yet the fact that SPDs are bad at picking up actual demographic dynamics at the intra-generational scale does not in any way undercut the method´s usefulness in long-term trend analysis – which is its actual purpose and that it does rather well. What is more, SPDs do appear able to pick up on short-term real processes when the underlying process consists of a distinct threshold, such as a marked regime shift in environmental productivity. Although seemingly negative, these results actually strengthen the information value of SPDs for human ecodynamic purposes, as they demonstrate how long-term human demographic trajectories not only track, but also result from, environmental conditions.

4.6 Palaeoenvironmental data

A major concern of this project has been to situate human demographic and cultural trends within an ecological frame of reference, but also more specifically, to correlate time-series of cultural and environmental trajectories. This is a novel contribution of my work, never systematically attempted previously in Norway. Doing so has entailed a strong reliance on various proxy-based palaeoenvironmental reconstructions. Yet, many of the critical factors pertaining to proxy-based palaeodemographic reconstructions also apply to the environmental realm, in addition to proxy-specific methodological and sampling issues.

Not all climate and environmental reconstructions are of equal relevance. Although this seems on the verge of banality, paper 1 made an explicit attempt at evaluating what proxies prove most relevant in the specific context of Holocene Arctic Norway. The rationale behind all palaeodemographic and environmental comparisons in my work has been to consider a range of terrestrial and marine proxies of as high quality and relevance as could be mustered. This led to the realization that the classic Greenland ice cores were a highly inappropriate proxy for regional and even local environment/climate across the globe. Although a relevant proxy for hemispherical/global climate trends, it has become increasingly clear from a range of other proxies that the ice cores do not provide a good reflection of variation in northern Fennoscandian conditions and that the scale and susceptibility of human responses to environmental changes correspond more to the regional scale. Aggregate climate patterns, although important, are not the most adequate drivers of human ecodynamic changes.

What is turning out to be truly relevant proxies are those that track various forms of energy availability and environmental productivity at a regional scale. Basic temperature trends are the first, crude step, yet much more useful are time-series representing changes directly linked to biological activity – such as growing season intensity, primary production etc. However, such reconstructions are less frequent. Fortunately, the palaeoenvironmental record of Holocene Fennoscandia is particularly well-studied in the global context. The “Arctic Holocene proxy climate database” has been important in this regard, acting as an open repository for palaeoenvironmental reconstructions (Sundqvist et al. 2014). Reconstructing past trophic relations and productivity regimes is, however, very difficult. A great strength of this work is the contribution of a new palaeoproductivity reconstruction of inner fjord conditions within the study area (Jørgensen et al. 2020). This was provided courtesy of Jochen Knies at the Norwegian Geological Survey after personal contact. This is a great advancement of H.E. research in the area, as this palaeoproductivity record is of a sufficiently high resolution and tracks productivity changes in an environment of utmost relevance to the demographic and adaptive features of the population under study.

This thesis relies heavily on the assessment of multi-proxy trends in order to track past environmental and human ecodynamic trends. Throughout the 4 papers, a total of 19 palaeoenvironmental proxies are employed and analyzed in unison with human activity proxies, as provided by the archaeological record. Given the advantage of studying an area well-covered by palaeoenvironmental reconstruction, a set of proxy selection criteria was established early on. Most important were palaeoenvironmental proxies of maximal inherent resolution, highest assumed ecological relevance to human economic exploitation, geographical location (prioritizing proximity to the study area) as well as sufficient time-depth to provide useful comparison with the archaeological trends. Each paper that presents multi-proxy evaluation of human ecodynamics (papers 1-3) has made the effort of consolidating palaeoenvironmental parameters of both the terrestrial and marine ecosystems of relevance to the study area.

As my work has a strong interest in human/coastal- relations, it was particularly important to couple a range of proxies from aquatic ecosystems with the human population trends. The papers have made a selection of such proxies on the basis of covering the variation in the evolution of coastal currents, potentially specific to the inner coastal and outer shelf-break oceanographic conditions, along with freshwater lakes. All proxies are presented according to protocol in the specific papers, however, particular attention should be directed at the contribution of a novel, marine palaeoproductivity reconstruction in this work from the Malangen fjord. It is therefore given some extra focus here.

The Malangen core sample is derived from inner coastal waters in the major fjord system on the southern border of the primary study area of this thesis (**see Fig.1**). Although other palaeoproductivity proxies exist within the primary study area of this thesis and thus may intuitively appear to be of even higher relevance, none are of comparable, ecological relevance. For example, numerous marine geological core samples have been retrieved from the Ingøy Deep trough outside NW Finnmark. However, these core samples are the product of a depositional environment very different from that of the coastal waters that were navigated and exploited by prehistoric people, both in terms of the great depth, the currents, and their significant distance off-shore (actually beyond the shelf break). In sum, and most importantly, the Ingøy Deep trough cores track a very different component of the marine ecosystem that that of the coastal conditions. Ocean current regimes are markedly different between the Atlantic water transported by the North Atlantic Current and the coastal current running along the shoreline (Junttila et al. 2014). These differences should therefore be controlled for and undermines the relevance of marine proxies from the shelf break for H.E. purposes.

Furthermore, there are numerous marine geological samples that have been retrieved from coastal waters and inner fjord locations within western Finnmark. Ideally, some of the samples from Lopphavet (e.g. core R1MC85) could have been used, as they derive from the waters just south of Sørøya Island where the *Stone Age Demographics* project has been doing fieldwork annually throughout the project period. Unfortunately, they lack ^{14}C dating, are of insufficient time-depth for the current purposes, and have not been analyzed for palaeoproductivity – or a combination of the above (Finne et al. 2007; Pathirana et al. 2015:table 1). Such inadequacies are the case for the other inner coastal marine cores in the area.

The Malangen fjord palaeoproductivity proxy is therefore unique, being the only palaeoproductivity reconstruction from inner coastal waters in NW Norway – that also satisfies the criteria of data resolution, time depth, ^{14}C dating and ecological relevance. Although on the southern edge of the primary study area, it is well within the overall study area of this thesis. The sampling station is within a major fjord system that connects the primary and overall study area on the NW coast of Norway. I would therefore argue that the contribution and use of the Malangen core sample is much more than just a compromise; it is particularly suitable for the purposes of this thesis. Its use has also been specifically recommended by Jochen Knies, who is has retrieved and analyzed all the marine cores discussed above – that is, both the Malangen, Ingøy Deep and the Lopphav samples.

4.6.1 Equifinality: Chicken and egg-problems of causation in human ecodynamic research

In H.E. research we want to get at the causes and effects of change in integrated human/environmental systems. Currently, we are able to reconstruct timeseries that demonstrate change. Yet the change we observe is mostly the effect of some underlying cause we cannot identify with high precision or certainty: "the co-occurrence of two or more phenomena does not imply causation by any one of them, only the likelihood of interdependence and close relationship, possibly through a third variable. […] Pattern is not cause; arguments from correlation are research problems, not explanations. For the latter, we need to identify and understand the mechanisms in relationships" (Dincauze 2000:32).

Then how do we identify causality in interrelated human ecodynamic systems replete with feedback mechanisms? This question is paramount to advancing H.E. research and urgent to my own work. This is in need of acute attention, with multiple follow-up studies. I am not able to provide any in-depth account of these issues here, beyond pointing to important factors that might influence the correlation between palaeodemographic and -environmental reconstructions. As stated by Fitzhugh: "Ecosystems condition the field of evolutionary possibilities for change at any given moment. Collectively, this bivalent, time-space dynamic makes explaining ecological change uniquely challenging. How can we explain the evolution of system components (e.g., populations and ecological communities) and aggregate systems themselves?" (Fitzhugh et al. 2019:1079).

It has become commonplace to compare population trends with past environmental trends, performing pattern recognition with the aim of identifying correlated fluctuations. However, correlation does not equal causation. Thus, we are often left with large-scale trends that might coincide or not, without sufficient accounts of the plausible causal mechanisms connecting climate and human demography. Human and environmental variables are obviously connected, but exactly how is debated. This has been a major concern of mine, and I have taken the stance that the only way of coupling them, is by way of developing middle-range human ecodynamic mechanisms. Only then may we account for the mediation of large-scale environmental variability through local ecology that impacts human demography and adaptive strategies.

There are multiple problems when correlating various proxy-based reconstructions. However, a rather surprising result of the human ecodynamic research agenda in reconstructing past human demographic change is that palaeodemographic models may function as an indicator of environmental productivity. This is bewildering, considering that demography is the result, not the cause, of environmental productivity. But as demonstrated in Tallavaara and Jørgensen (In press), human demography represents long-term mean environmental productivity quite well.

The causal relationship of demography with the other system components of human societies/groups is neither linear nor mono-causal. This is because demography is equally explanans and explanandum – that is, the result as much as the driver of other variables. This may be conceived of as the "chicken and the egg"-problem of causation in H.E. research. Human populations are open-ended systems that fundamentally rely on and interact with the environment. As such, the attempt of integrating various proxy datasets are prone to "**equifinality**", in that no single set of causes can be readily assigned to each unique situation or circumstance (Dincauze 2000:31). This is also known as underdetermination or multiple realizability. This opposes portrayals of human history as a "simple closed system" only acting and reacting to its own, internal dynamics [see critique of the static population assumption in, Section 2.2].

The issue facing human ecodynamic research (in terms of equifinality) is a subset of the more general issues of integrating multidisciplinary research. Dincauze (2000:24) has identified three measures of success: "*complementarity* of different data sources, *consistency* between data sets, and *congruency* of scale". Complementarity entails that different data sources contribute to a grander union than if kept separately. Consistency implies that the proxy data actually inform of the same phenomena, which can be particularly hard to determine. Congruency entails fit of comparison between data sources, given the often disparate spatial and temporal scales tracked by different proxy records. There are no clear-cut answers to how we may best achieve these goals in practice. In fact, there has been surprisingly little public debate on this issue within H.E. research. One point that has become clear in my and others research is that the spatiotemporal scale of palaeoenvironmental reconstructions matter significantly when compared to scale relevant to human adaptation and demographic responses. My papers have all pointed out (and demonstrated in paper 1) that hemispherical climate proxies, such as Greenland ice cores, carry little weight in explaining human demographic responses in particular study areas. This is why paper 3 contained a rather direct critique of the use of solar activity as a global proxy for energy availability in (Freeman et al. 2018). Instead, human populations and the ecosystems they reside in are significantly governed by regional-scale environmental parameters. Arctic Norway is a striking example of this. Despite its high-Arctic latitudinal position, the oceanography and climate impacts of the North Atlantic Circulation produce Atlantic/Boreal like conditions far surpassing anything at a comparable latitude. With regionally specific climate, regionally specific flora and fauna follows. The result is regionally distinct ecosystems in which human populations are but one biological component. Correspondingly, an important result of my work is the demonstration of ecosystem-specific correlation between population and environment. The maritime population has been shown to be more strongly regulated by changes in the marine environment, than that of the terrestrial. Such patterns would not have been possible to identify without high-resolution, local palaeoenvironmental data of direct relevance to human resource exploitation.

Taking this into account, I tried to develop more complex dynamic conceptions of how the human population was casually connected with multiple external factors in my papers. For instance, this was directly discussed in paper 3 when stating that:

> *"Although our results suggest that climate is the most likely explanation for the spatial synchrony between the northern Norwegian and western Finnish hunter-gatherer populations, other mechanisms may still be in play. The trend correspondence between population size, climate, and adaptive strategies highlights the more generalized problem of what should be ascribed causal primacy among demographic, environmental, and technological factors in bringing about synchronous adaptive strategies: Did marine resource exploitation vary independently of population size, or did the maritime specialization result from changes in population size, thus being density dependent?"* (Jørgensen et al. 2020:9).

This encapsulates the paradoxical (chicken and the egg) properties of human ecodynamics relations. The complexity of the matter is furthered by the number of technical and proxy-specific issues that contribute to the uncertainty of coincidental trends, and consequently, makes it difficult to ascribe causal responsibility to particular variables. Comparing, correlating or otherwise combining different data types is not without associated risk. This risk increases manifold when qualitatively different proxy data records are conjoined. This issue faces all human ecodynamic research, and mine is no exception. Some important factors are listed below and illustrated in (Fig.12):

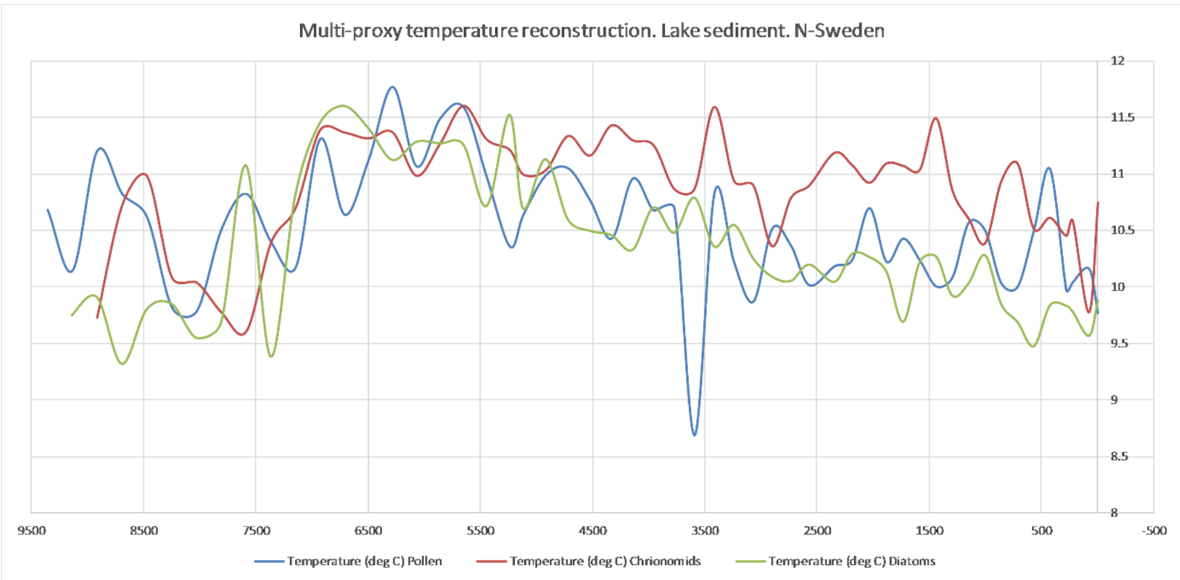

Figure 11 Three separate climate proxies extracted from the same lake sediment. Despite general trend correspondence, there are differences in ecological response time and magnitude to climate variability. Data from (Rosén et al. 2001, cf. Rosén et al. 2003).

- Data resolution
    - The usefulness of every palaeoenvironmental reconstruction is partly determined by its resolution. Archaeological and human ecodynamic research primarily operate at more detailed scales than what is tracked by environmental data. The emphasis on long-term trends mitigates some of this problem, yet the relevance of proxy records must always be evaluated.
- Different time scales
    - Beyond the sampling-induced resolution that may reduce the comparative potential of human ecodynamic studies, there is also the inherently different scale of natural phenomena of interest to various disciplines. Geologists, botanists, palaeontologists

and archaeologists seek to solve different problems, and thus perform specific sets of analyses that may not be directly comparable across disciplinary boundaries, i.e. due to incompatible scales of the underlying causation.

- Different response times (lags)
  - Different proxies are associated with particular response times, even when thought to track the same environmental change/event.
- Different proxies can be susceptible to different drivers and pathways
  - Even in cases were various proxy records are thought to track the same, overall environmental trajectory, the individual proxies my track the same change by way of particular causal/ecological pathways. This is important to account for when using them as proxies for humanly relevant environmental factors.
- Different sensitivity to shared drivers
  - In cases where different environmental proxies are thought to respond to a shared driver, each proxy has its own response sensitivity. The implication is that the magnitude of response is proxy-specific and not comparable across proxies without the aid of transfer-functions.
- Problems related to transfer functions
  - The transfer-functions used to compare different proxies by means of a common unit (often temperature, salinity, productivity etc.) are susceptible to errors in calibration among proxies due to the issues mentioned above.
- Regional differences
  - The selection of climate proxies and their individual reconstructions has major implications for the result when correlated with human population proxies. It is important to employ the most relevant climate proxies based on combined criteria of particularly high resolution and geographical proximity, as well as satisfying a criteria of diversity of proxy types. When selecting climate data for covariation testing, both the spatial and temporal proximity as well as scale and resolution has to be considered in order to achieve meaningful comparison.
- Statistical assumptions not universally applicable across proxies
  - Many palaeoenvironmental reconstructions rely on specific methodological assumptions when submitted to e.g. time-series analysis. It has been demonstrated that a number of natural phenomena display cyclical behavior over various temporal scales and time-series analysis is to a large extent geared towards the identification and analysis of cyclical patterns. However, this assumption is not necessarily suitable for timeseries of human data. Although it may be in many cases, the premises built into particular analytical tools need to be considered when performing multi-proxy analysis, and when comparing phenomena of human and natural origin (see; Carleton et al. 2018).

4.7 Ground slate tool data

Besides palaeodemographic and –environmental data, this thesis also draws on more traditional material culture data. The most important category of archaeological artifact data is provided through lithic analyses of ground slate tools, as presented in paper 4 (Jørgensen 2020). It is fundamentally important to understand the technological component of human ecodynamic trends, as technology is the intentional mediator between human physiological needs for sustenance, the economic means of production and the environmental space of opportunities. Hunting and processing tools are the economic means of production within HG societies. As specific tools have particular functions and tools are specialized for particular types of prey, changes in tool-kit composition through time may arguably be used as an indicator of adaptive shifts. Yet what technologies are suitable as a proxy for economic and adaptive strategies in an area mostly devoid of organic preservation?

What is possibly the most significant lithic technological change in Holocene Arctic Norway is the introduction and pervasive use of slate tool technologies 7500-2500 cal BP. Slate technology is valuable as an indicator of adaptive strategies given its particular maritime function. However, its situation within a wider human ecodynamic context has never been investigated: “It was early on pointed out that slate technology seems to be a trademark of maritime hunter-gatherers in the circumpolar north … However, reviewing the global literature on slate technology reveals a striking pattern of peaking interest during the late 1970s and a near total neglect ever since” (Jørgensen 2020:3). My idea has therefore been to test the correlation between population and technological dynamics, by constructing a comparable time series of slate technology, termed a “Slate Abundance Index” (SAI). This is done by equating the relative proportion of slate tools in lithic assemblages with the degree of maritime intensification. Through tracking the relative proportion of slate artefacts and debitage frequencies relative to that of other lithic raw materials through time, the index could then be compared to established palaeodemographic models in the area.

Remarkably, the results demonstrate that the quantitative and typological magnitude of slate technology, strongly correspond to the dynamics of both population size and environmental productivity (Jørgensen 2020). In fact, all stages of the slate industry´s evolution (innovation, development and final decline) correspond neatly to the human ecodynamic trend. This is taken to indicate **maritime intensification** within the integrated, socioecological system. Ground slate technology appears to have been a critical variable in this system, acting as an “enabling technology” for the adaptive success of a maritime specialization taking place during the mid-Holocene, corresponding to packing at the coast and the apparent population depletion in the interior: The unmatched plasticity and potential for standardized production in slate instigated a scale economy mitigating what is usually very high investment costs in establishing maritime technologies. The scalar effect (decreased cost per unit with increasing output) of slate technology resulted from its suitability for the multi-component replaceable-part technologies of maritime hunting and fishing. Slate reduced the handling costs of mass-procured marine resources and increased the quality of processed sealskin-covered boats, driving the evolution of open-ocean, deep-sea fishing. Ultimately, slate technologies increased the adaptive fitness of the mid-Holocene Arctic Norwegian population, and thus, contributed to the population growth of the 6000 cal BP cycle.

An important question has been to what extend socio-technical abilities of a population may transcend environmental productivity and thus allow some leeway in braking free of the environmental deterministic population regulation. Several of my papers have therefore explored the role of subsistence technologies in bringing about the mid-Holocene population boom and bust-cycle in

Arctic Norway. As has become apparent through both this and other works in human ecodynamic research, the socio-technical ability of humans to transcend environmental parameters (carrying capacity) for extended periods is rather limited prior to state formation. Despite what seems to be a partial contribution of maritime resource intensification to the population trajectories across northern Fennoscandia, the trend correspondence between demographic and palaeoproductivity trends draws the causal efficacy of subsistence strategies into question (Jørgensen et al. 2020).

4.7.1 Slate data representativity

Despite the early recognition of the "maritime connection" of slate tools, slate technologies have been remarkably unpopular among lithic specialists. Paper 4 sketches out multiple reasons for this, yet the most likely one is the number of limitations inherent to slate assemblage data. These limitations consist of the general poor recording of most slate assemblages following old excavations, the minimal reduction waste produced from ground tool production, which leave little diagnostic debitage suitable for *chaîne opératoire* investigation, as well as the apparent (archaeological) preference for cryptocrystalline lithic technologies comparable to that of the European mainland.

For my studies, I conducted extensive lithic analyses of a large proportion of the slate tool assemblages hosted by the Arctic University Museum in Tromsø, which curates the archaeological record of Arctic Norway. There are currently are 2294 objects classified as slate tools in the study area, constituted by slate knives (1366) and slate projectiles (928) as reported in the www.unimus.no database. A subset of 900 diagnostic slate tools (408 knives and 392 projectiles) were subjected to morphometric analysis. That is, 40% of the original slate tool population. However, the original population is comprised of all stages of tool fragmentation, from complete artefacts to minor fragments. The study sample exclusively comprises tools that contain a minimum number of diagnostic traits. Only projectiles with preserved bases that carry information on tang, barbs, geometric section, width and thickness are included. Accordingly, only knives with a preserved handle/blade-junction, intact blade width and thickness, as well as being clearly worked (although not necessarily finished or grounded) are included. Based on these selection criteria, a high number of projectile fragments were excluded (medial and distal fragments) as well as undiagnostic knife fragments. I qualitatively estimate that 70-80% of diagnostics tools in the museum collections have been analyzed. The representativity of the analyzed sample is demonstrated in (Fig. 13), when compared to the baseline dataset at the museum. The baseline dataset displays a distinct bimodal distribution - a trend that is fully reproduced in the analyzed sample.

Data was collected personally by going through magazine boxes at the museum during 2 weeks in the summer of 2018 and 4 weeks in the summer of 2019. Adding further data is increasingly time consuming as the sampling strategy focused on the largest slate assemblages and moving into smaller slate assemblages consecutively. Previous classifications were disregarded, as they have mainly been applied in an unsystematic and eclectic manner in existing studies/reports. This was supported by uncovering frequent typological inconsistencies. Thus, I tried to avoid descriptive classifications during data collection, saving this for post-analysis. All projectile types have been regarded as a common class, disregarding the distinction between "arrow heads" and "spear heads" that are used in the UNIMUS database. I also performed a general review of slate assemblages from across the duration of the slate tool tradition, in order to pinpoint major changes and developmental trends. This evaluation relied on multiple attempts at constructing quantitative indexes of variability, such as the ratio of knives-to-projectiles through time. In addition, a qualitative evaluation was made of trends in period-specific technological concepts within the slate tradition.

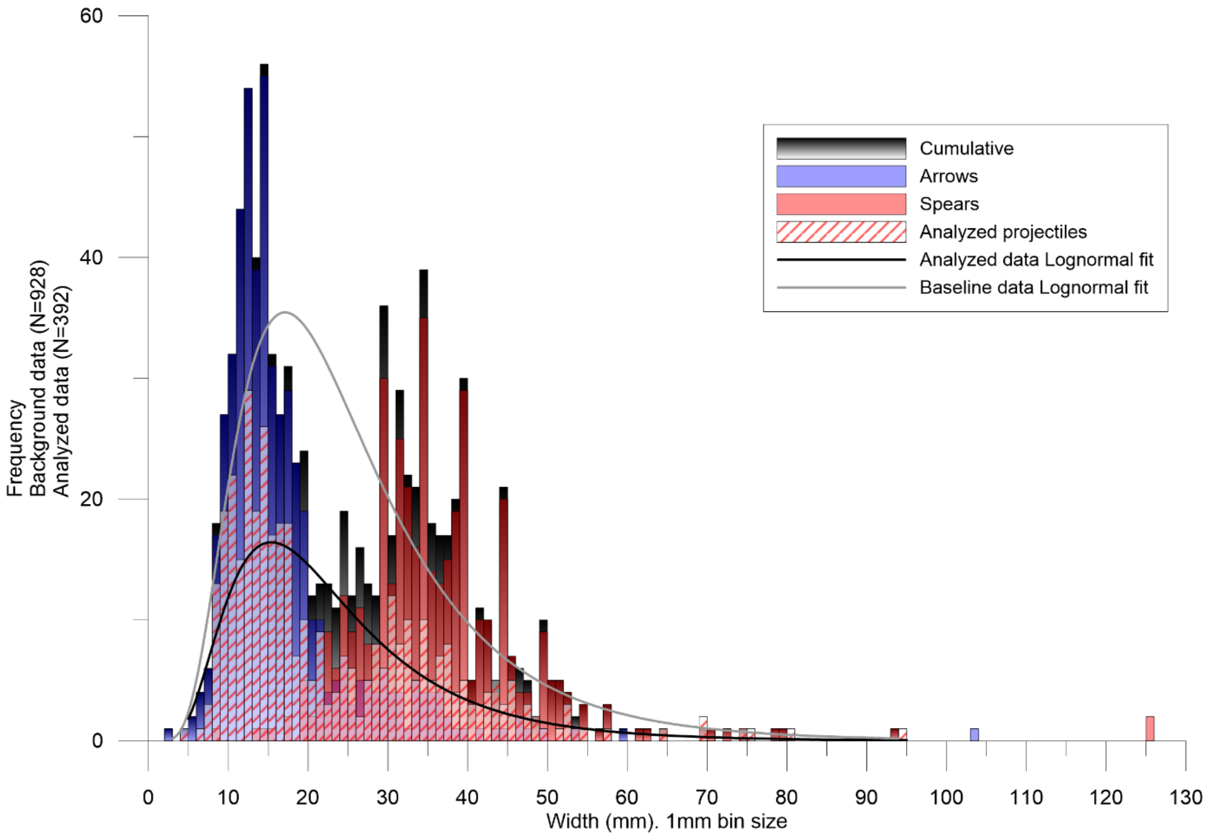

Figure 12 Demonstration of data representativity in the slate tool analyzes. Histogram comparing the baseline dataset and analyzed dataset on projectile width. Note the distinct bimodal distribution. Cumulative plot refers to the accumulation of baseline datasets of arrows and spears, not including the dataset specifically analyzed. The baseline and analyzed datasets are in strong correspondence, as visualized by the fitted lognormal distributions.

It has been an ambition to overcome the hiatus in slate technology research by analyzing data in the aggregate rather than by recording detailed technological traits. As my project mostly concerns large scale human ecodynamic patterns, a great variety of measures and analyses performed during the lithic studies have not been relevant to include in the doctoral papers. The results of these investigations will be published elsewhere, focusing more directly on the typological, chronological and production sequence of various slate tool types. Such detailed morphometric and technological results are outside the scope of this thesis.

5 Future directions – gaps to fill

My results demonstrate multiple cycles of increased population numbers. Yet, viewed from the opposing angle, each population cycle seems to have been followed by periods of drastically reduced population numbers and human presence, in particular between 5500-4500, 3500-2500 and 2000-1600 cal BP. Testing whether these intervals represent real demographic downturns or an artefact of sampling, make for obvious targets in future research. Regardless of the objectivity or precision of the models presented here, one cannot argue with the great value demographic reconstructions have for identifying future avenues for advancing research. It is self-evident that no individual researcher or group of researchers could muster the insight and overview presented by big data-analyses.

There is also the issue of a potential underrepresentation of small, less intensively settled sites. Non-habitation sites should receive more attention, as there has been an almost exclusive focus on house-pit sites. If we are to reconstruct past cultural systems, a singular focus on habitation sites is not sufficient. Sites of specialized economic (or other) function(s) need to be investigated more closely, so we may separately identify the material correlates of logistical contra residential mobility. My personal hobbyhorse is promoting cave sites, which make for a readily available and highly promising site type that should be prioritized in future research as they hold a wealth of preserved information we rarely get elsewhere.

5.1 Absolute population numbers

On the global, methodological side, we need to move on to absolute population numbers. A great weakness of most palaeodemographic studies is the near exclusive treatment of demographic reconstructions as relative units – however, see (Müller 2015; Schmidt and Zimmermann 2019; Zimmermann et al. 2009). Although a practical necessity for most purposes, relative demographic studies easily get detached from actual demographic processes. Truth-grounding of palaeodemographic results is best achieved through comparison with real demographic systems. I suspect that a number of the demographic interpretations put forth within the current regime will be difficult to uphold in future reexaminations for this very reason. This is something that has been directly commented upon, in pointing out the troubles of making growth-rate estimates on archaeological proxy data (Tallavaara and Jørgensen in press).

Although I have not gone into absolute population numbers myself, this is something I wish had been possible to do. The real magic happens when abstract population dynamics are transformed into absolute population numbers, as real demographic, social and ecodynamic structures can only be properly understood through concrete numbers. Micro-level studies of house contemporaneity and inferences regarding local community size seems to be the most obvious way ahead given the particular characteristics of the Arctic Norwegian archaeological record. But even if this can be done for one or more sites, it will be difficult to upscale reliably. I rather suggest that palaeogenetics may be the most rewarding avenue.

5.2 Population genetics

In the local context, there is a pressing need for better spatial and temporal coverage of human osteological remains. The prospects for great advances in palaeodemographic knowledge in Arctic

Norway suffers from the dismal preservation of organic and osteological remains. The ideal case is being able to reconstruct human genomes from spatially and temporally diverse individuals within the region. With time-series palaeogenetic data we can truly get closer to both demographic and human ecodynamic research objectives. It would make it possible to estimate absolute population numbers, demographic bottlenecks, admixture, inbreeding etc. So far only one individual of Stone Age origin in Arctic Norway has been sequenced (Günther et al. 2018). The low number of burials containing preserved osteological remains is an issue. However, a number of individuals are known from the Late Stone Age/Early Metal Age transition, at e.g. Gressbakken and Nyelv sites (Renouf 1989; Simonsen 1961). These make for obvious candidates for future research. The same goes for the number of disarticulated human bones and teeth from both Storbåthellaren (Utne 1973) and Kirkhellaren (Gjessing 1943) cave sites. However, the value of palaeogenomic studies fundamentally rely of sample size. Thus, the sequencing of existing skeletal remains should be accompanied by a focused search for more human osteological remains with significant age and temporal distribution (for instance by locating dedicated burial grounds, if they exist).

5.3 The “more people, more stuff”-assumption

The ethnographic record may be used to test the assumed linear correlation between population increases and greater deposition of datable materials. This essentially is a question of site formation processes and particularly one concerning discard behavior. It has already been established empirically through ethnoarchaeological studies that discard behavior is regulated by the degree and type of mobility. Mobile and sedentary communities display different depositional behavior (Murray 1980). For this very reason, the method is susceptible to circularity. As pointed out by Renfrew (1973:46), palaeodemographic reconstructions necessitate a source of time-series data that is independent of the adaptive strategy of the reconstructed populations. However, the impact of mobility and adaptive strategies on long-term archaeological visibility at the landscape-scale is not known. The study of site formation processes is not as lively a subject as it used to be, but the need to establish the “more people, more stuff”-assumption empirically could provide the circumstances necessary to reinvigorate a topic most fundamental to the archaeological discipline. The same goes for experimental studies. It is equally necessary to combine empirical and experimental studies with simulations that test the impact of various degrees of residential stability on SPDs. Bayesian modelling of dwelling/site reuse seems a promising avenue for progress. Connecting high-resolution site-scale Bayesian models with macro-scaled SPDs should be the ultimate goal. The preservation conditions for making this coupling is not ideal in our area. I suspect settlement data from Jomon Era Japan would make a stronger case (e.g. Habu et al. 2011), yet this has not been tested at this point.

5.4 Cultural transmission links between population size and technology

Cultural transmission theory (CTT) needs to be explicitly applied in the analysis of the archaeological record of Arctic Norway. This is because the transmission of knowledge and practices constitute the obvious middle ground when connecting macro-scale demography and population ecology with micro-scale adaptive choices and technology (Shennan 2006; Walsh et al. 2019). CTT is also important in moving beyond the more static conceptualizations of the “complexity debate”, in which technological complexity is conveyed as either the linear or non-linear product of population density

(Bettinger et al. 2006; Collard et al. 2016; Henrich 2004; Vaesen et al. 2016). An example to follow is that of Jordan (2014:2), stating that "technological traditions exhibit heritable continuity". The implication is that particular technological regimes need to be investigated at least partly as particular historical trajectories, susceptible to founder effects and path dependency – thus not necessarily reducible to mono-causal and linear causation by variables such as population size or environmental conditions. Other important studies with clever design include (Derex et al. 2018; Roux 2013; Shennan 2009 - and works therein).

Paper 4 was an explicit attempt at doing this, by tracing the co-evolution of population size, environmental productivity and means of production by way of slate technologies. However, more detailed experimental, biochemical and geological provenience studies of the slate industry are required. The ambition should be to increase the typological-chronological resolution, ascertain functional development and, most importantly, develop a fuller understanding of the production sequences of slate technologies and how they may be susceptible to particular selective pressures.

I propose that the spatially skewed and discontinuous uptake of ceramic technologies in Arctic Norway would make for a highly suitable case study for applying CTT in human ecodynamic research. This would facilitate a move towards explaining the push and pull factors for the uptake and maintenance of ceramic technologies, which is currently lacking. Other candidates displaying similar dynamics in the area and thus constituting interesting cases for CTT studies, are that of metallurgy and agriculture.

5.5 Compile continental trends

Finally, I propose that Arctic Norwegian archaeology engage more actively in contributing to continental-wide efforts of compiling data and results. A number of European projects are in place for realizing this and related goals. It is becoming increasingly clear that solving archaeological problems require data efforts that transcend national borders. Signing up for large-scale integrative research might help move out of the isolationism and exceptionalism occasionally expressed in Arctic Norwegian archaeology. The low intensity of archaeological sampling of adjacent areas in northern Sweden, Finland and Russia has contributed to this trend.

In particular, it would be most helpful if more joint research efforts were established with Russia, as most human adaptive features seem to be structured by latitude. Arctic Norway is currently conceived as placed atop of the world, but may (for all we know) more properly be described as the western margin of important demographic, technological and cultural dispersive centers in Russia. This has been touched upon in my own and others research, when emphasizing the Lake Onega and White Sea area as a likely distribution channel (if not epicenter) of cultural changes also witnessed within the study area (Hood, Helskog, et al. in press; Jørgensen 2020). Yet without more direct investigations of compatible methodology and data quality, sufficient progress is lacking. In addition to more empirical, comparative work, it is also recommended that such studies are carried out with the express intent of exploring source-sink dynamics (e.g. Kawecki 2004; Schollmeyer and Driver 2013).

I have tried to contribute to this agenda through my work by compiling and comparing trends at the local, regional, international and circumpolar level. For instance, the comparative analysis of ecodynamics trends in Norway and Finland in paper 3, and the circumpolar synthesis of paper 4. Furthermore, an explicit attempt was made in paper 2, when including Arctic Norway in the continental-wide mapping of the adaptive response to the Thera eruption and consequent Bronze Age collapse (Risch and Meller 2015) (Fig.14). Although eventually removed from the paper due to space limitations, I suggest similar integration of continental or regional trends make for important research avenues in the future.

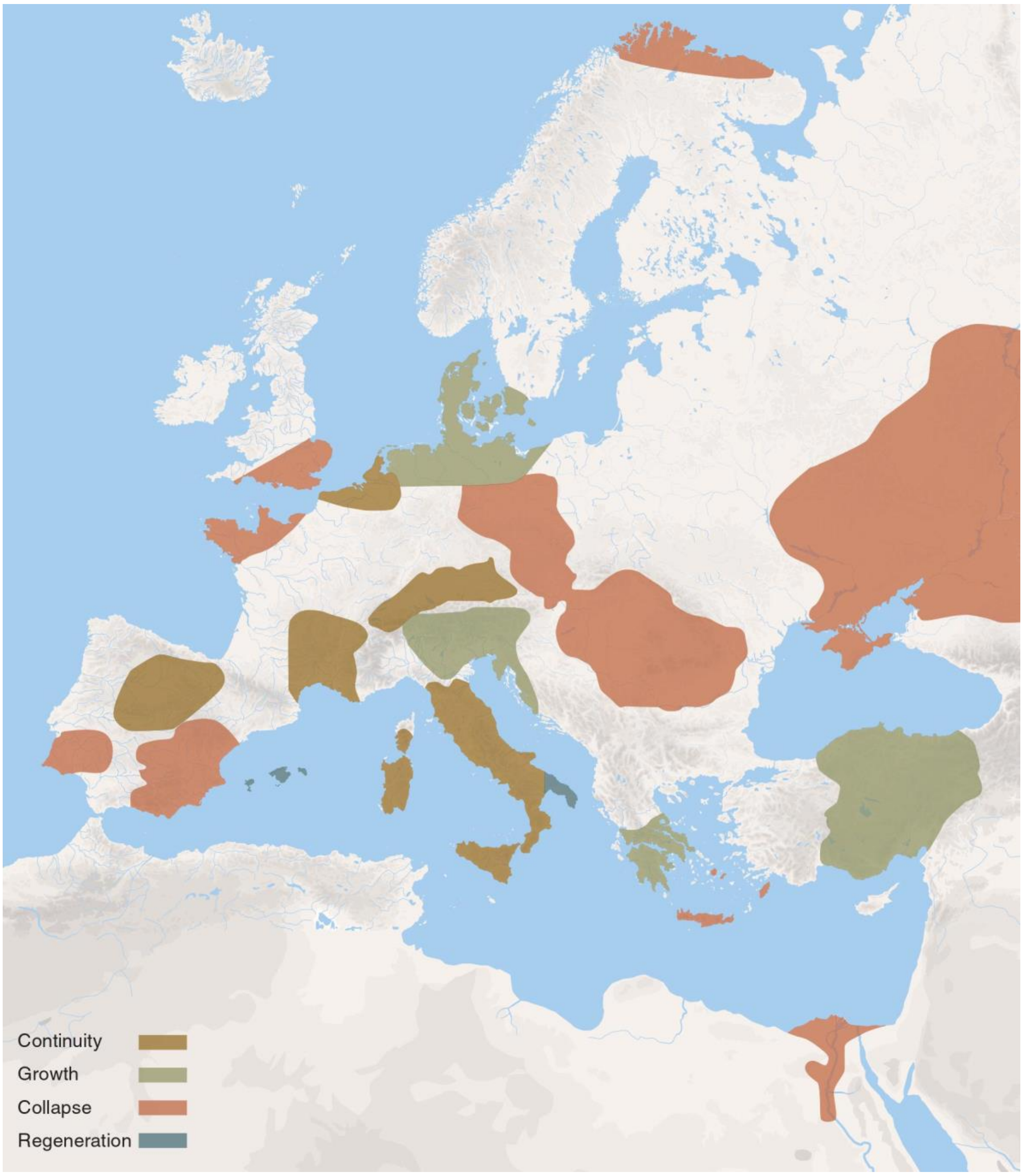

Figure 13 Mapping of the societal response to the Thera 3550 cal BP eruption across Europe, associated with the Bronze Age collapse. The response in Arctic Norway has been included in the continental overview. Redrawn and adapted from (Risch and Meller 2015).

6 Conclusion

In summarizing the contribution of this thesis it is useful to relate the outcome to the initial research objectives. This project set out with the overall ambition of investigating the human ecodynamic trends of Holocene Arctic Norway, specifically by reconstructing relative population change and how it relates to environmental factors within the timeframe of 12.000-2000 cal BP. This grew out of a local research historical background mainly emphasizing short-term and site-scale issues in demography, economy and settlement patterns, as well as relying on a “static population assumption” in which change predominantly was viewed as the result of internal (social) factors. Population level demographic change had not previously been studied, and more broadly, palaeodemography as a systematic study was new prior to this thesis. The overall ambition was then operationalized as a set of concrete research objectives:

a. Reconstruct relative population changes
b. Compare with relevant palaeoenvironmental records
c. Provide detailed case studies of human adaptive responses to ecological change
d. Establish middle-range causal mechanisms connecting macro-scale climate forcing with micro-scale human risk reduction strategies, by way of aggregated demographic, technological and ecological effects.
e. Track the evolution of maritime adaptation in the region.

A major contribution of this work has therefore been the reconstruction of relative population changes, through radiocarbon-based palaeodemographic modelling (research objective A). A general, increasing trend across the Holocene was identified, including three significant, positive boom-and-bust cycles, centered on 5800, 4000 and 2200 cal BP. An important impact of my work is increasing the awareness of the *dynamic* nature of population level human demography, and the commonality with which population fluctuations occur. I have stressed the fact that high-frequency demographic change and abrupt, as well as gradual, population fluctuations are the norm rather than the exception. This has been demonstrated by on-the-ground ethnographic census data, simulation studies and is now firmly established by the accumulated mass of concurrent palaeodemographic results from across the globe.

This project has been set within the analytical framework of Human Ecodynamics, which essentially involves “the dynamic integration and co-evolution of human and natural system, or socioecosystems” (Fitzhugh et al. 2019:1077). This perspective itself is a novelty to the region, investigating the nested external and internal properties of past socioecological systems. Accordingly, the project contributes important balance to the prior emphasis of internal factors by exploring the ecological and adaptationist drivers of change among the past populations of prehistoric Arctic Norway. This has been done by extensive comparison between demographic modelling results and relevant palaeoenvironmental records (research objective B). Most importantly, the results demonstrate strong trend correspondence between palaeodemography and environmental trajectories. The results are important because they demonstrate ecosystem-specific human/environmental correlations. Case in point, the population has been shown to be more strongly regulated by changes in the marine environment, than that of the terrestrial.

This was further investigated through several detailed case-studies of human adaptive responses to ecological change (research objective C). Highlights of these investigations are the abandonment of semi-sedentary and larger coastal sites in favor of increased mobility and inland resource exploitation following a set of climate deteriorations 4000-3500 cal BP inducing decline among both human and reindeer populations. There is also the remarkably synchronous demographic and adaptive changes among geographically disjunct populations in Arctic Norway and western Finland 6000 cal BP, with increased reliance on coastal adaptive strategies, apparently driven by a shared increase in marine productivity. This is possibly the most direct and explicit demonstration of the Moran effect among prehistoric human populations in the global literature so far. As such, this work has contributed to an increased understanding of coast/inland dynamics of prehistoric Arctic Norway. The previous mantra of distinct populations interacting at particular nodal points in the landscape during the mid-Holocene, seems less plausible when considering the results presented here. This is also more in line with recent investigations in the interior. The results rather suggest extensive population packing at the coast in concert with an apparent de-population of the interior during the 6000 cal BP demographic cycle.

As has become apparent through both this and other works in human ecodynamic research, the socio-technical ability of humans to transcend environmental parameters (carrying capacity) for extended periods is rather limited prior to state formation. The results presented here contribute to and corroborate the commonly reported demographic trajectory across mid-Holocene Europe, consisting of a marked population boom and bust-cycle. It has been claimed that the striking pattern of a pronounced mid-Holocene population peak across large spatial scales is more important than is often expressed, as the correlated human ecodynamic changes seem to be independent of adaptive strategies (foragers or farmers) (Jørgensen 2018:12). As such, the issue of socio-technical abilities to transcend environmental parameters is an important element to this thesis as it has major demographic implications. Several of the papers have therefore explored the role of subsistence technologies in bringing about the mid-Holocene population boom and bust-cycle in Arctic Norway. Despite what seems to be a partial contribution of maritime resource intensification to the population trajectories across northern Fennoscandia, the trend correspondence between demographic and palaeoproductivity trends draws the causal efficacy of subsistence strategies into question (Jørgensen et al. 2020).

What is possibly the most important general contribution of my work is the attempt at establishing middle-range causal mechanisms connecting macro-scale climate forcing with micro-scale human risk reduction strategies, by way of aggregated demographic, technological and ecological effects (research objective D). The modelling results, climate comparisons and results from reviewing trends in the archaeological record were integrated in a multi-scalar analysis. The importance of this lies in being able to identify adaptive strategies in mitigating/responding to and coping with/benefiting from environmental changes. This was investigated in greatest detail concerning the strong trend correspondence between not only the coastal population trajectory and the primary productivity of the local coastal environment, but also with the introduction, development and final decline of the ground slate industry. The positive identification of correlated relations between environment, demography and technology gets to the very core of human ecodynamic research, and arguably, archaeology at large. Although my work consistently argues for the primary causal efficacy of environmental factors in shaping human demographic trajectories, being able to determine the role of technology (the extrasomatic means of adaptation) in mitigating external change and instigating adaptation is crucial when attempting to piece together the micro/macro scales of integrated socioecological systems.

In approaching this goal, the project has been concerned with the evolution of maritime adaptations (research objective E). As such, I have argued that ground slate technology was a critical variable, acting as an "enabling technology" for the adaptive success of the mid-Holocene maritime specialization: The unmatched plasticity and potential for standardized production in slate instigated a scale economy mitigating the investment costs through its suitability for the multi-component replaceable-part technologies of maritime hunting and fishing. Slate reduced the handling costs of mass-procured marine resources and increased the quality of processed sealskin-covered boats, driving the evolution of open-ocean, deep-sea fishing. Ultimately, slate technologies increased the adaptive fitness of the mid-Holocene Arctic Norwegian population, and thus, contributed to the population growth of the demographic cycle. Importantly, the relation between the distribution of slate technology, maritime adaptive strategies and highly productive northern ecotones is not a regionally specific phenomenon. It rather seems to hold true for multiple and distinct high-latitude hunter-gatherer populations. This is corroborated by both formal and informal comparative analyses with other Circumpolar populations that display maritime adaptive strategies. My work should therefore be seen as a contribution towards explaining the convergent evolution among circumpolar maritime groups.

In sum, this project has contributed several new methodological and analytical approaches rarely touched upon in the region. Hopefully, it has demonstrated the merits and usefulness of adaptationist, causal-mechanistic thinking in tackling long-standing issues in both local and global archaeology.

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Papers

Paper 1

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The palaeodemographic and environmental dynamics of prehistoric Arctic Norway: An overview of human-climate covariation

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ABSTRACT

This paper presents the first palaeodemographic results of a newly assembled region-wide radiocarbon record of the Arctic regions of northern Norway. The dataset contains a comprehensive collection of radiocarbon dates in the area (N = 1205) and spans the 10,000-year period of hunter-gatherer settlement history from 11500 to 1500 cal BP. Utilizing local, high-resolution palaeoclimate data, the paper performs multi-proxy correlation testing of climate and demographic dynamics, looking for hunter-gatherer responses to climate variability. The paper compares both long-term climate trends and short-term disruptive climate events with the demographic development in the region. The results demonstrate marked demographic fluctuations throughout the period, characterized by a general increase, punctuated by three significant boom and bust-cycles centred on 6000, 3800 and 2200 cal BP, interpreted as instances of climate forcing of human demographic responses. The results strongly suggest the North Cape Current as a primary driver in the local environment and supports the patterns of covariance between coastal climate proxies and the palaeodemographic model. A mechanism of climate forcing mediation through marine trophic webs is proposed as a tentative explanation of the observed demographic fluxes, and a comparison with inter-regional results demonstrate remarkable similarity in demographic trends across mid-Holocene north and west Europe. The results of the north Norwegian radiocarbon record are thus consistent with independent, international efforts, corroborating the existing pan-European results and help further substantiate super-regional climate variability as the primary driver of population dynamics regardless of economic adaptation.

1. Introduction

The effects of climatic and ecological variability on hunter-gatherer populations has been a central topic to archaeology worldwide (Berglund, 2003; Binford, 2001; Kelly, 1983; Kelly et al., 2013). Yet despite the rapid accumulation of palaeoclimate records for the North Atlantic region during the last decades, no systematic effort has been made to relate climate proxy data to the archaeological record of northern Norway. This paper aims to do so by evaluating the potential demographic responses of northern Norway's Stone Age population to Holocene climate fluctuations. Such a long-term study of Stone Age demographic patterns can contribute to our broader understanding of resilience, vulnerability and adaptation in the North Atlantic region, which has been explored intensively for much later time periods (Dugmore et al., 2012, 2007; McGovern et al., 2007).

This paper presents the first prehistoric population model from northern Norway. The empirical basis for the palaeodemographic model is a comprehensive regional radiocarbon database, newly assembled for this purpose. The model was compared to local, high-resolution palaeoenvironmental proxy records, testing for both event and long-term correlation. The data (N = 1205 radiocarbon dates) cover a 10,000-year period of hunter-gatherer adaptations, from initial colonization at 11.500 cal BP until 1500 cal BP. As this marks the first overview of large-scale compilation and analysis of north Norwegian radiocarbon data, the paper provides a somewhat thorough presentation of the regional database.

The reconstruction of past population histories has become a hot topic in archaeology over the past decade. Regional and long-term palaeodemographic models based on summed probability distributions (SPD) of large sets of calibrated radiocarbon dates have been constructed for a variety of geographical and temporal units covering: Europe (Bevan et al., 2017; Downey et al., 2016; French and Collins, 2015; Tallavaara et al., 2015), north America (Chaput et al., 2015; Peros et al., 2010), Oceania (Attenbrow and Hiscock, 2015; Smith et al., 2008) and east Asia (Crema et al., 2016; Fitzhugh et al., 2016) to name but a few. Simultaneously, the severity and scale of Holocene climate variability has long been thought to be of minimal magnitude compared to the Late Pleistocene, which saw repeated and dramatic climate shifts

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(Burroughs, 2008). Yet, intensified research into Holocene climate dynamics has identified significant events, moving beyond the general story of Holocene climate as a steady rise and fall in favourable conditions centering on the Holocene Climate Optimum (HCO) (Moros et al., 2004, p. 2113). The identification of Holocene climate variability has sparked a renewed archaeological interest in reviewing potential covariation between Holocene cultural and environmental systems (Kelly et al., 2013; Shennan et al., 2013; Tallavaara and Seppä, 2012), though the causal links connecting the two variables in specific case-studies are disputed (Armit et al., 2014).

Palaeodemography as a systematic topic is new to north Norwegian archaeology. Research has mainly focused on settlement patterns and seasonality during the Late Stone Age (7000-4000 cal BP). However, there are two subjects of demographic relevance that have seen considerable attention:

1) The degree of *sedentism* during the Late Stone Age has been much debated. The original models proposed mainly a seasonal mobility pattern (Gjessing, 1956; Simonsen, 1975, 1965, 1976). Responding to these works, others claimed that Late Stone Age sedentism had been substantial (Olsen, 1994; Renouf, 1989, 1984; Schanche, 1994). Others emphasize settlement variability (Andreassen, 1985; Engelstad, 1984; Helskog, 1984, p. 57; Hesjedal et al., 1996, p. 205; Hodgetts, 2010, p. 50).
2) The few estimates of *settlement sizes* that exist have ranged from minimalist accounts, 1–7 pit-houses per site (Engelstad, 1983; Helskog, 1984), to large aggregations of up to 30 + pit-houses per site (Olsen, 1994; Schanche, 1994; Simonsen, 1965), resulting in wildly disparate population estimates.

As both topics have been addressed mostly at the local site level and without much inter-site integration, the conclusions are of limited value at the regional level. The current state of research is thus rather inconclusive and mostly applicable to eastern Finnmark County. This is due to a heavy research emphasis on the eastern record, stemming from the pioneering work made by A. Nummedal, G. Gjessing and P. Simonsen during the mid 20th century. The population history and settlement dynamics of the western coast has therefore remained somewhat of a blank spot (c.f. Hesjedal et al., 1996, p. 205). The absence of preserved prehistoric faunal remains in Troms County and western Finnmark has furthermore hampered the development of a settlement model for the west coast. In addition, marked geographic and eco-climatic differences in the area are likely to have sustained different settlement patterns and subsistence strategies along the east-west and coast-inland axes. It may therefore be unwise to project a model adapted to the eco-geographical conditions of eastern or inner Finnmark onto the west coast. In sum, these factors drive the need for large scale, regional demographic and palaeoenvironmental synthesis.

2. Regional setting

The study area encompasses the two northernmost Norwegian counties (Troms and Finnmark), covering a landmass of approximately 75.000 km^2 (Fig. 1). Both in modern and historic times the main population has been located along the coast, which is known to provide exceptionally productive fishing. Despite mild coastal winters (−2 to −10 °C) and two months of midnight sun the area is north of the main agricultural boundary, and foraging made a substantial part of the subsistence strategy up until WWII.

The extensive coastline is perforated by islands and deep fjords, which along the west coast are flanked by towering mountains, while the eastern coast connects to the flatter Baltic shield of the Russian Kola Peninsula. The eastern-central inland area is a low-altitude mountain plateau.

Positioned between the 68–71° latitude, the area exhibits substantial climatic differences along the east-west axis. The western coast receives approximately twice the amount of annual precipitation (1030 mm) compared to the eastern coast (560 mm). The variation in effective temperature (EF) between the west coast (11.11 °C) and the east coast (6.09 °C), reflects the influence of warm Atlantic water masses conveyed by the North Atlantic Current in the west. The EF reflects biologically relevant climate parameters, providing a measure of the duration of an area's growing season (calculated as in (Binford, 2001, p. 59) - see SI equation 1). A threshold of 10 °C marks the limit of < 30 days without killing frost per year. The values obtained for eastern Finnmark correspond to northern Greenland/Canada, while Troms and western Finnmark correspond to coastal British Columbia (Canada) and Alaska (U.S) (cf. Binford, 2001, p. 67).

3. Materials and methods

The last decade has produced a number of sophisticated computational methods for analysing large data sets. The introduction of "big data" analysis into archaeology, arguably, has enabled us to infer more fine-grained demographic fluctuations than ever before. In the dates-as-data approach inherent to the current methodology (described below in section 3.2), all the results are based solely on radiocarbon dates. As age determinations in themselves are independent of typology and periodization, such data provide a separate demographic proxy in the archaeological record.

3.1. Data collection

The regional radiocarbon database was collected through a review of available dates from multiple sources. The following procedure was established in order to collect the most complete database as possible. (Data collection for this paper ended at 15/10/2017. Some minor adjustments and data increase might be expected beyond this point).

- Every radiocarbon date with a confirmable cultural origin within the timeframe of 11.500–1500 cal BP from Troms and Finnmark counties was compiled into the regional database. The termination date of 1500 cal BP is set some centuries after the partial introduction of agriculture and adoption of iron technology in northern Norway, in order to cover the entire period of Stone Age adaptations. This ensures the highest possible continuity and comparability of data and takes into account the statistically unreliable edging-effects introduced by the applied methodology.
- The only cultural entity excluded from the database is hunting pits, as they produce contextually unreliable dates. Otherwise, every confirmable archaeological date was included, ranging from settlements and graves to ceramic residues.
- Data was collected by a thorough review of all published material, both in the academic literature and excavation reports.
- Unpublished dates were collected through personal communication with individual researchers and groups, as well as going through museum archives for unpublished and unfinished material.
- Data collected by the regional heritage authorities are also included, as they occasionally date samples collected during field surveys.
- A date lacking confirmable information on any variable resulted in exclusion; a total of 115 dates (9,54%) were omitted (see SI database).

As the database contains radiocarbon age determinations conducted over the last 50 years, the quality of contextual information is highly variable. In order to mitigate such errors, a set of strict quality criteria had to be introduced (see section 3.3). Most radiocarbon samples dated prior to 2000 were sent to the national radiocarbon laboratory at NTNU Trondheim, which keeps record of all dates handled at the lab. I retrieved all their archived data originating from the respective study area, and was able to crosscheck with the existing dataset, correct errors and add extra material.

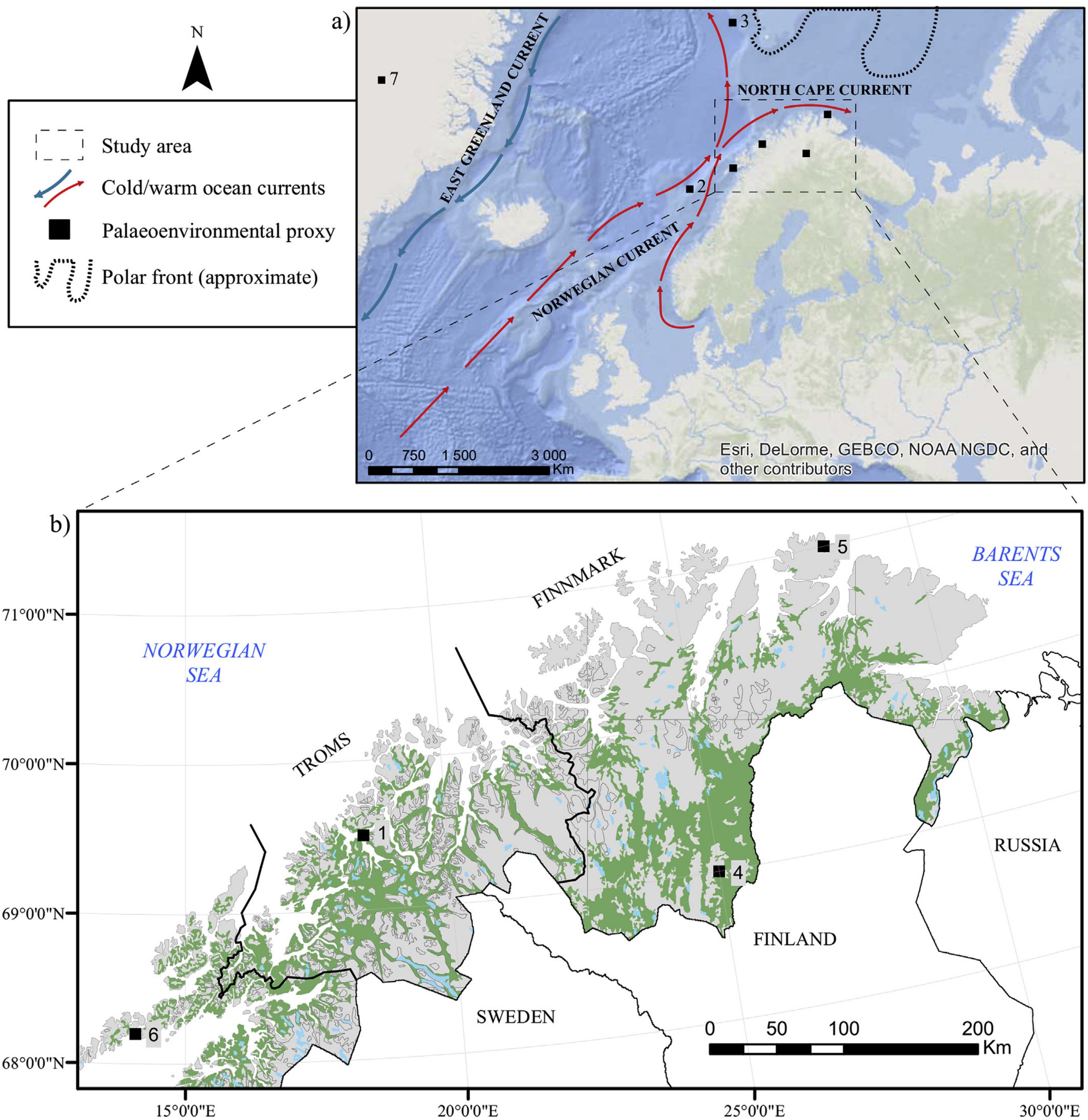

Fig. 1. a) Regional overview indicating study area, major oceanographic properties and an approximation of the oceanic polar front, marking the contact zone of Atlantic and Arctic waters in the Barents Sea and southern border of sea ice formation (Engelsen et al., 2002, p. 82; cf. Loeng, 1991). b) Troms and Finnmark counties in northernmost Norway constitutes the data catchment area. Map data provided by Kartverket. Numbered black dots in both (a) and (b) correspond to the palaeoenvironmental proxy records presented in Table 1.

Dating methods also vary. Prior to 2000, most radiocarbon dates was made with conventional (β) beta-counting. A high proportion of the post-2000 dates are conducted using the more accurate and precise accelerator mass spectrometry (AMS) method, making up about half of the dataset. Despite the relatively high number of conventional dates, the average standard deviation is $\Delta T = \pm 63{,}25$. Considering the size ($n = 1205$) and temporal span (10 000 years) of the data set, the ΔT is comfortably within the required range in order to minimize the impact of spurious statistical noise, as established by simulation experiments (Michczynska and Pazdur, 2007; Williams, 2012).

The frequency distribution of uncalibrated dates is presented in Fig. 2.

3.2. Methods

Summed probability distributions (SPD) – also known as probability frequency distributions (PDF) – proceed through collapsing the probability distribution of individual radiocarbon dates into a combined probability function of N dates. The graphic output may then be evaluated in terms of relative population densities, and population

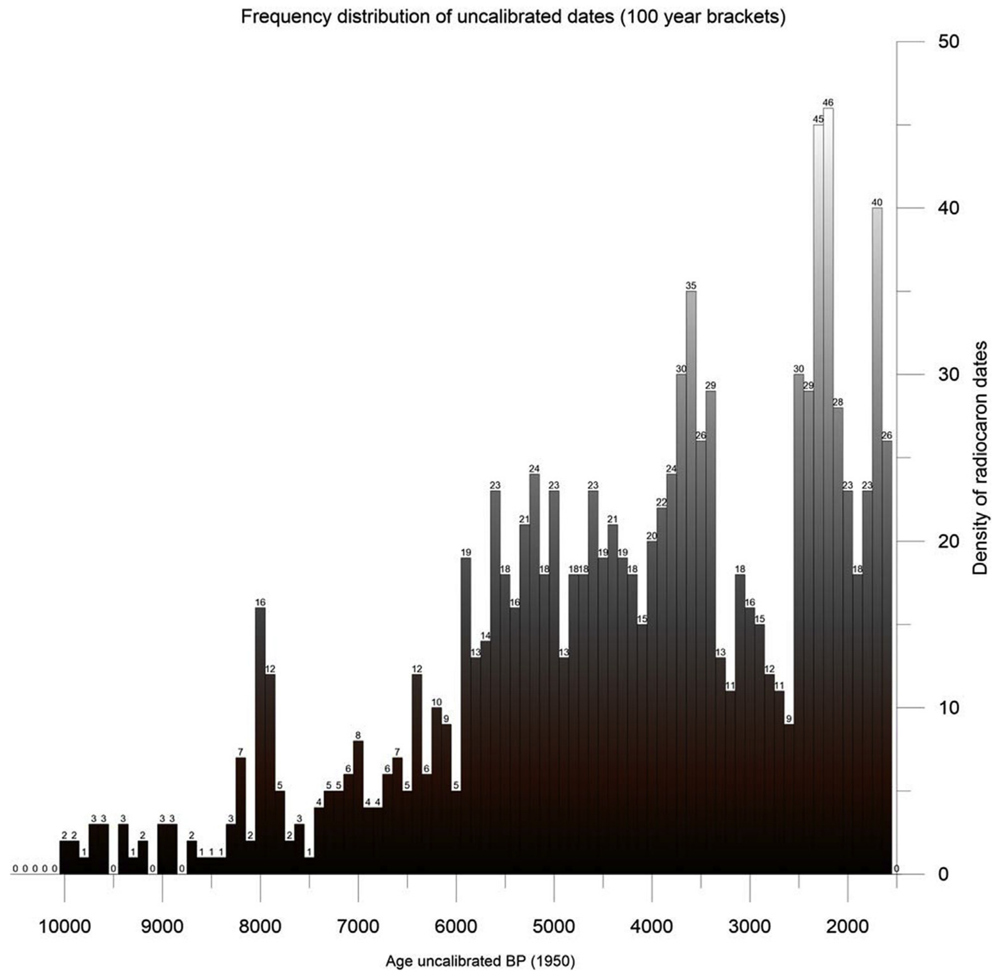

Fig. 2. Frequency distribution of uncalibrated dates in the database before statistical processing. 100 year interval bar plot.

dynamics may be interpreted based on the topography of the probability distribution. The SPD method provides palaeodemographic estimates based on the premise that radiocarbon dates may function as a proxy for past populations – known as the "more people – more stuff"-theorem. This is done by assuming a direct and constant deposition rate of datable materials per person through history - originally known as Rick's (Rick, 1987) "dates as data"-proposition. The application of the method has increased vastly during the last decade, bringing renewed interest in palaeodemography. This interest has also resulted in the establishment of standard procedures as well as the identification of systematic errors (Brown, 2015; Contreras and Meadows, 2014; Crema et al., 2016; Timpson et al., 2014; Williams, 2012).

A critique of purely visual and qualitative description of SPD results has been put forth (Brown, 2015; Contreras and Meadows, 2014; Crema et al., 2016, p. 5; Shennan et al., 2013; Williams, 2012). In order to evaluate whether the SPD-results may be considered genuine or merely an artefact of calibration curve interferences (such as packing and thinning) or random sampling effects, simulations of uniform and exponential growth functions were performed with the Monte-Carlo Summed Probability Distribution Method (MCSPD - see (Crema et al., 2016; Shennan et al., 2013; Timpson et al., 2014)) based on the R software code originally presented by (Crema et al., 2016). Based on the methodology developed in (Shennan et al., 2013; Timpson et al., 2014), the SPD results are compared to a statistical envelope null-model, in which randomized calendar dates sampled from the distribution defined by the null-model are back-calibrated into radiocarbon dates. A number of simulation runs (N_{sim} = 1000) are performed in the production of the statistical envelope making the random "background-noise" (cf. Crema et al., 2016, p. 5). Any deviation outside the 95% confidence interval of the envelope null-model marks the SPD results as statistically significant under the null-hypothesis of either uniform or exponential growth.

In the present study, all statistical analyses (calibration, the summing of probability distributions, taphonomic correction and simulation of null-hypothesis distributions) have been performed using the Intcal13 and Marine13 calibration curves (Reimer et al., 2013) in the R environment for statistical computing (R Development Core Team, 2015). Marine reservoir correction was only applied to materials of marine origin or if ^{13}C values suggested marine origin (e.g. seal bones or ceramic food crust residues) and the date was not already corrected at the laboratory (cf. Skandfer, 2003, p. 233). If lacking ^{13}C values, ceramic dates were compared to charcoal dates from the same context to evaluate the degree of correspondence. Marine calibration was only applied if ceramic dates diverged from charcoal dates from the same context.

The demography/climate co-variation analysis was conducted using a point-to-point correlation test of raw palaeoenvironmental data and exponentially smoothed (spline = 0,97) SPD values. Exponential smoothing was preferred over running mean estimates, as it introduces less artificial temporal shifting of the SPD results. Covariation testing was done in order to transcend the standard procedure for comparing multi-proxy datasets, which mostly consist in visual comparison of trends. Despite the many problematic issues connected to the point-to-point correlation methodology (e.g. issues of scale and resolution), I maintain that the approach may contribute to the standard visual comparison as it counters some of the subjective errors introduced by the visual method. In strict statistical terms, it does not provide reliable results, though it can be indicative of the degree of covariation, which is of interest when – critically - held up against other proxies.

Recent tests have demonstrated rather convincingly that the summation methodology does provide reliable results and that the previous objections are ineffective (Edinborough et al., 2017). Though kernel density plots may be preferred in certain instances (Ramsey, 2017), the main results are presented as a SPD in order to maximize resolution. A kernel density plot is attached in the SI as well (see SI Fig. 1).

3.3. Combination of dates

Different sites make different contributions to the regional radiocarbon record for a number of reasons not exclusively determined by past depositional practices. It is therefore necessary to compensate and weigh the contribution of each site through binning-procedures. The common practice for combining dates belonging to, or assumed to be associated with, the same depositional event, is to combine all dates belonging to a single site within a predetermined age-bracket – usually 200 years (Timpson et al., 2014, p. 550). The original set (N = 1205) was sifted through automatic binning procedures in “R” in which dates of common contextual origin within 200 year brackets are combined. The final dataset consists of (n = 873) binned dates. Due to the structuring of archaeological sites within the study area and the corresponding excavation practices, the dates were combined at the individual feature-level. This time consuming and unconventional approach produces more precise and demographically interesting results at a higher resolution for the following reasons:

1) The most prominent feature of the north Norwegian Stone Age record is the numerous pit-house settlements along the coast. Pit-house features of all ages are visible as clear depressions on the modern surface and are well recorded. An estimated 6000 pit-houses have been recorded in the two counties, and the radiocarbon dates predominantly stem from such pit-house features.
2) The depositional history of a multi-feature site is more properly represented if the radiocarbon record is catalogued by individual features instead of as a single site. The standard single-site combination approach risks conflating what really are separate events.
3) Investing some effort into breaking the dataset down to the feature-level results in a generally higher data resolution which may be better at identifying spatiotemporal dynamics. Importantly, only well-defined habitation structures have been singled out for this procedure. Dates not directly associated with individual habitation structures have been combined using the normal “site”-level binning procedure. My claim is that such binning procedures provide more demographically interesting data in allowing for individual demographic units (i.e. houses) to be realistically represented in the dataset.

This approach is a direct response to the administrative organization of the north Norwegian archaeological record, in which “a site” may include multiple features dispersed over a large area. The very character of the north Norwegian archaeological data favours such an approach, as the large majority of dates stem from multi-feature sites integrated into complex patterns of reuse. The procedure for combining dates employed here does not run the risk of strongly over-representing certain sites or features, because most dated habitation features are only represented by a single age determination. In cases where there are multiple determinations per feature, the procedure combines dates within 200 year bins. There is more likely to be some issues of under-representation, as most sites that have produced radiocarbon dates at all have dated only a minimal fraction of the actual number of habitation features present at a site. For instance, one of the most iconic pit-house sites in Fennoscandia - Gropbakkeengen, Varanger Fjord, East Finnmark - has only produced a total of 4 radiocarbon dates despite consisting of approx. 100 pit houses (Simonsen, 1961, Fig. 35). The two dates from House 3 are combined as they fall with the 200-year bin, while the individual dates from House 4 and Mound C are retained as they represent clearly separate features of significant temporal separation. The resulting contribution of this important site to the regional SPD after binning is but three age determinations. Furthermore, common dating practice until recently has been to retrieve only 1–2 dates per house feature no matter the dating potential, targeting the construction phase. As such, what was actually a long occupational history of intensive re-use spanning centuries to millennia of multiphase occupation may result in the same radiocarbon signal as a short single occupation. Consequently, as previous dating practices were not able to pick up on occupational frequencies, and short-term occupation sites are likely to be more numerous, these events might therefore be over-represented at the expense of multi-phase occupations.

3.4. Source critical factors – biases

A number of critical responses have been directed at the SPD-methodology, which has led to the identification of some important biases that merit attention in every application. The biases can broadly be separated into three categories: a) creation bias, b) preservation bias and c) investigation bias.

3.4.1. Creation bias

A founding condition of the SPD-methodology is the expectation of a linear and constant relation between population densities and the deposition of datable materials, the “more people = more stuff” theorem. The theorem posits that the deposition of datable materials per person is rather uniform and constant regardless of the situation. Intuitively, the depositional rate and character of any population are highly contingent phenomena. Regardless of the potential bias introduced by differences in depositional rate and character through time, it is considered to be of less importance to this dataset, as the influence of major shifts in subsistence or social structure is restricted to the terminal millennium of the sampled period. The selection of temporal span for this paper was partially made with this factor in mind, trying to circumvent the introduction of unnecessary uncertainty.

3.4.2. Preservation bias

A generally acidic bedrock and the virtually non-existent soil accumulation provide unfavourable preservation of organic materials in the area. Being exposed to both chemical decomposition and unprotected physical erosion, nothing but lithic debitage is usually recovered during excavation. Thus, there are some real issues concerning preservation bias in the current dataset. The Mesolithic (11500-7000 cal BP) seems to have been characterized by a highly mobile lifeway, leaving few permanent structures beyond the odd tent ring and consequentially, datable charcoal is rarely preserved. Thus Mesolithic data are potentially underrepresented. Despite this, several pit-houses have recently been dated to ˜9000 cal BP (Gjerde and Hole, 2013, p. 241). The potential for early and late Mesolithic pit houses have been noted (Grydeland, 2006), though currently, rarely any have been dated outside the middle Mesolithic.

Furthermore, there is the issue of isostatic uplift. The study area exhibits dramatically different shoreline displacement regimes. Particularly the outer areas of the western coast were subjected to the Tapes transgression between 8000 and 6000 cal BP. The difference between the inner-outer fjords and along the east-west axis means that coastal sites in the outer area of the western coast that were occupied just prior to the transgression most likely would have been destroyed, and are therefore underrepresented in the dataset. There is also the conflating effect of palimpsests introduced by the transgression, as transgressed settlements may have been re-settled at a much later stage when the shoreline displacement had returned to pre-Tapes levels. The isostatic uplift and Tapes transgression target specific areas and affect archaeological periods differently, thus introducing some preservation bias. There is also the potential negative influence on preservation by the 8.2 cal BP Storegga tsunami in low-lying areas. The tsunami had a minimum vertical run-up of 3–4 m along the coast of Finnmark (Romundset and Bondevik, 2011). The archaeological consequences would be the introduction of geographically skewed preservation bias along the coastal isobase gradient.

A taphonomically corrected SPD model was simulated in order to evaluate the results, applying the taphonomic correction function developed by (Surovell et al., 2009). As organic matter is rarely preserved in northern Norway, it may be relevant to apply the taphonomic corrective function to the data in this particular case. However, the correction is not applied in the main graphic results in order to reduce the amount of statistical processing. The reader is therefore encouraged to evaluate the taphonomically corrected model in the supplementary information (SI Fig. 2).

3.4.3. Investigation bias

There are significant differences in data coverage within the research area. In general, the coastal area has better data coverage and is likely to be less biased than the inland. The western coast has seen multiple large-scale development-led excavations since the 1990′s in addition to some research excavations. In contrast, the eastern region has been the focus of research excavations since the 1950′s, but without any major development-led excavations thereafter. This has produced a disparity in both data quantity and quality amongst the regions, especially concerning radiocarbon dates. Furthermore, a case can be made that the paramount work made by Simonsen (1961,1963) in eastern Finnmark was such an important precedent for later research that it constitutes a strong case for path dependence and founder effects (Mahoney, 2000). As a result, the eastern material is potentially subject to research biases due to prolonged research efforts targeting specific cultural events/phases. The eastern data has been plotted against the original Younger Stone Age (YSA) chronology for the area (Helskog, 1980, p. 54) in Fig. 3. As is visible, focus has been directed at YSA phase 2 and 3, while phase 1 and 4 have barely contributed to the radiocarbon record. In addition, the chronology was highly dependent on relative dating of artefacts and poorly supported by radiocarbon dating, making a skewed contribution to the regional database (N = 219 dates) considering the degree of research intensity. The research excavations undertaken by a small handful of researchers along the eastern coast were conducted mostly prior to the widespread use of radiometric dating. The impact of the investigation bias might therefore be less pronounced than would have been the case under recent dating protocols, which produce significantly larger date samples.

The focus on coastal sites has resulted in a radiocarbon record unrepresentative of the interior. As Norwegian archaeology is currently almost exclusively rescue-driven, this bias is not a consequence of incommensurate research strategies, but more due to economic activities and population centres being located along the coast and therefore instigating more archaeological surveying.

As the effects of investigation biases are disputed (Timpson et al., 2015; Torfing, 2015a, 2015b) it is beyond the scope of this paper to make a thorough review of their potential effects in the area. The eastern data is therefore not represented as a separate region in the climate comparison case study below, and instead homes in on the western region as a best case scenario. The eastern dates are still included in the overall presentation of the macro-scale demographic model, justified by the Law of Large Numbers (Timpson et al., 2015, p. 201).

4. SPD results

The summed probability distribution of the 873 binned dates (based on 1205 individual determinations) was plotted against two simulated null-models (uniform and exponential growth functions). This has produced the relative population development as demonstrated in Fig. 4. There appears to be a general population increase over time, which is disrupted by a pattern of boom and bust-cycles, centred on the mid to late Holocene. The early Holocene population numbers are markedly low and fall completely within the expected range of the exponential null-model. The following events deviate significantly from both null-model growth functions:

1. The twin peaks between 6500 and 5500 cal BP: A culmination of the development started in the early/mid-Holocene transition and ended with the abrupt downturn at 5500 cal BP.
2. An abrupt downturn at 3500 cal BP followed by a 1000-year long decline until 2500 cal BP.
3. The massive peak ca 2200 cal BP: A short-term boom and bust event of substantive proportions.

The general population development is most in line with the exponential growth model, albeit punctuated by the three highly deviating events making up a boom-and-bust cyclical pattern. This fits well with other research trends, in which boom and bust-cycles seems to be a demographic near-universal (Riede, 2011, 2009a,b). In contrast, under the uniform model there seems to be an inflection sometime after 7000 cal BP at which the general trend moves from significantly lower to significantly higher numbers than what is expected by the uniform null-model. The overall better conformity with the exponential growth model may be anticipated as the starting point is set at the initial colonization of an unpopulated area. The pattern might have been different if the dataset accounted for a limited time period within a long and continuous settlement history. A recent review paper (Zahid et al., 2016) demonstrated the growth function of hunter-gatherers to be similar to that of agriculturalists. This speaks in favour of the exponential model over the implied population stasis of the uniform model.

5. Climate comparison

Aiming to identify hunter-gatherer responses to climate variability, the correlation between climate and demographic dynamics was tested utilizing local, high-resolution palaeoclimate data. Both long-term climate trends and short-term disruptive climate events were included.

The Holocene climate of both Fennoscandia and northern Europe in general experienced a warming trend which culminated with the mid-Holocene thermal maximum, followed by colder, wetter and less stable conditions in the late Holocene (Balascio and Bradley, 2012, p. 268; Seppä et al., 2009; Walker et al., 2012, p. 268). When comparing local proxies to the general northern hemispheric record of climate variation provided by one of the Greenland ice cores (GISP2) there seems to be more divergence than conformity (Fig. 5) (cf. Fig. 10 in (Lauritzen and Lundberg, 1999)). This is to be expected if projecting modern properties of the North Atlantic Oscillation back in time, as conditions over Greenland are often opposite of that of N. Fennoscandia (Hurrell, 1995; Hurrell et al., 2003). This underlines the importance of using local proxies. As different climate proxies are sensitive to climate variation in specific ways, they may record the same climatic event differently in terms of strength, duration and response time, as well as being affected by time depth modelling and the transfer functions at use (Helama et al., 2013, p. 6; Rosén et al., 2003). The comparison of demographic and climate variability needs to be given a critical reading, allowing for some temporal shifting within and amongst the reconstructed results as it does not provide "spot on" wiggle-matching. This effect is visualised in (Rosén et al., 2003, 2001). The a-synchronicity is caused by the proxy-specific response time to variations in its local environment, creating so-called lead and lag effects (Lane et al., 2013; Roberts et al., 2015) - making it more reasonable to emphasize trends over short-term fluctuations. When comparing SPD's with palaeoenvironmental data, it is also necessary to keep the inherent probabilistic nature of SPD results in mind, which blur the accurate timing of events.

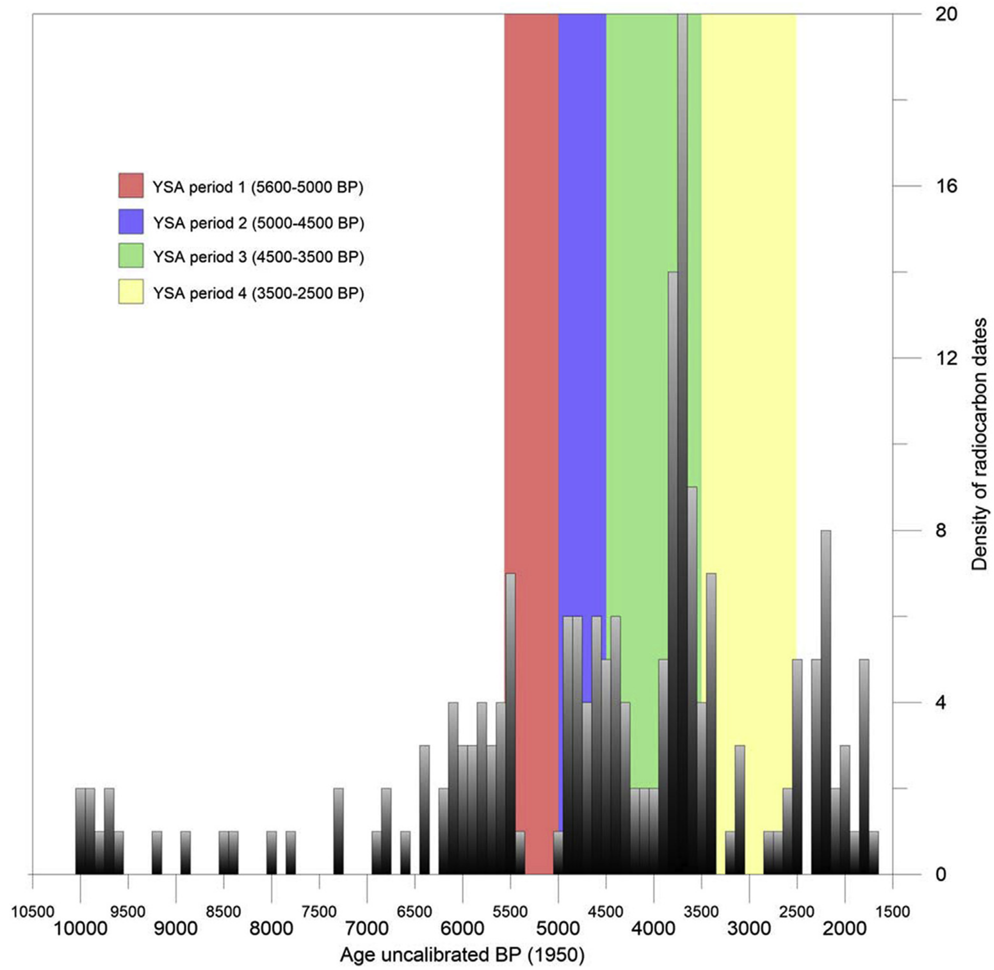

Fig. 3. Frequency distribution of uncalibrated dates from eastern Finnmark (N = 219), 100 year brackets. Illustration of potential influence of phase-specific investigation bias. Coloured bars correspond to the classic YSA periodization for eastern Finnmark in Helskog (1980) - which arguably directed investigative efforts.

5.1. The palaeoenvironmental record

The palaeodemographic results were tested against various relevant climate proxies collected from the Arctic Holocene Proxy Climate Database (Sundqvist et al., 2014). The selection was based on combined criteria of particularly high resolution, geographical proximity, diversity of proxy types and mapping various environments (marine/terrestrial, inland/coast). The aim was to identify potential covariations between human demographic trends and climate dynamics. In addition, correspondence between climate proxies was emphasized as to identify the most significant events that might be tested against the demographic model. Only those with the most significant and robust climate signals are presented here – see Table 1.

1) The marine core (JM98-1-PC) from the inner fjord environment of Malangen (Husum and Hald, 2004) maps changes to the near-coast current and is therefore of particular ecological interest to the identification of marine adaptations in prehistory. Unfortunately, the time depth is limited to 8000 cal BP and a centennial mean resolution of 185 years.
2) N. Atlantic marine core (composite record of JM97-948/2A and MD95-2011) from the Vorring plateau maps changes in the off-shore Norwegian Atlantic Current, with a multidecadal mean resolution of 15 years (Calvo et al., 2002). It is in general accordance with the inner fjord environment (Malangen) in exhibiting a general cooling trend from 5500 cal BP. Despite unequal resolution, both near- and off-shore climate reconstructions demonstrate similar event dynamics. This underlines the North Atlantic Current as the driving force of the marine and coastal environment.
3) High N. Atlantic marine core (GIK23258-2) is situated on the shelf break between Norway and Svalbard (Sarnthein et al., 2003). Just as the N. Atlantic core (Vorring), the High N. Atlantic core maps Holocene changes in the North Atlantic Current. Still, they differ in interesting ways. Despite GIK23258-2 being positioned at a considerable distance north off the Norwegian coast, it is included in order to control for changes in Atlantic water influx that would have differentially impacted these coring stations. The latitudinal N-S temperature gradient in the Barents and Norwegian Sea along the Norwegian coast has been established throughout the Holocene period (Hald et al., 2007), and thus provide valuable insight into the ocean current regimes and temporal variation in Atlantic water influx.
4) Dendrochronology-based climate reconstruction from northern Finland is included as a high-resolution local terrestrial baseline (Helama et al., 2010). Moving average smoothing (50 years) has been applied to the raw data of annual resolution for visualization purposes and identification of trends. Note that the magnitude of temperature variation in the dendroclimatology is less substantial due to these being averaged values. Please consult the original data for realistic annual temperature reconstructions. The data series is restricted to 7000 cal BP and does not cover the Older Stone Age.
5) A pollen core from a 71° N site (Over Gunnarsfjord) with a resolution of 89 years, representing the centennial scale (Allen et al., 2007). The core maps vegetation responses to changes in the coastal

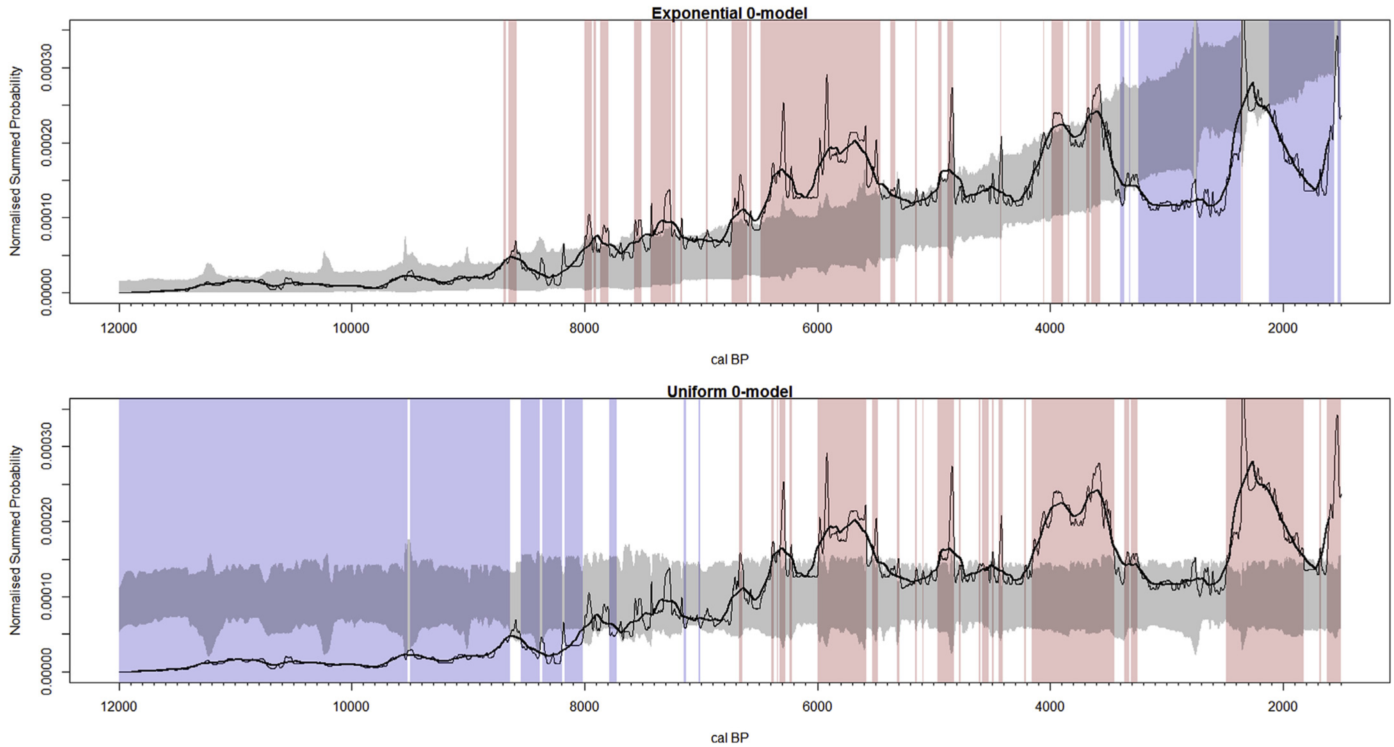

Fig. 4. SPD-results. Total dataset. Comparison of simulation results of the two null-models a) exponential model (upper), b) uniform model (lower). Positive deviation is marked in red, while negative deviation is marked in blue. $N_{sim} = 1000$. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

environment in the northernmost part of the study area, and complements the dendrochronological terrestrial proxy from the interior.

6) Sedimentary geochemistry from Lake Vikjordvatnet, Lofoten Islands, maps primary productivity in the lake environment, forced by temperature and precipitation "based on magnetic susceptibility, organic-matter flux, C/N, d13Corg, Ti concentrations, and mass accumulation rates" (Balascio and Bradley, 2012, p. 259). Henceforth organic-matter flux (OMF). Despite its on-land location, Vikjordvatnet may be viewed as a coastal proxy as it tracks on-land climate fluctuations on a landmass protruding into the near-coast current and thus mapping on-shore climate.
7) The GISP2 ice core from Greenland is included as a baseline for local comparison, as it provides the "global" palaeoenvironmental trend (Alley, 2000).

6. Human/climate covariation results

As the demographic model for the total study area (Fig. 4) covers large and climatically varied regions and data coverage is geographically clustered, the initial expectation of ambiguous climate covariation was confirmed. The most significant bias in this respect is the underrepresentation of the interior due to the low density of radiocarbon dates. Covariation with terrestrial proxies was therefore hypothesized and confirmed to be insignificant. As a best-case scenario (in terms of data quality), a separate SPD model was produced for the western coastal sites, which was added to the palaeoenvironmental covariation test (see SI Fig. 3 for simulation results). This model exclusively includes sites on the present day or prehistoric coastline in the thoroughly mapped region between Tromsø and Hammerfest municipalities on the west coast of Troms and Finnmark counties. The two palaeodemographic models and the seven palaeoenvironmental records are displayed in the muliplot (Fig. 5).

6.1. Correlation results

Table 2 presents the correlation coefficients when testing the SPD results of both total area and the west coast with the climate reconstructions of Table 1. These two areas were selected due to data quality considerations discussed in section 3.4.3. Only minimal data processing was performed. All climate proxy data is unprocessed with the single exception of a 50-year running mean of the annual resolution Lapland dendro. Testing suggest more powerful correlations are obtainable through minor, additional data smoothing – though this was not included here for robustness sake, i.e. not wanting to introduce unnecessary levels of artificial trending. SPDs were exponentially smoothed (spline = 0,97).

The strongest correlations were obtained for the coastal sites of the data rich western coast SPD and near-coast aquatic proxy of the Malangen fjord and general trend conformity with near-coast organic matter flux from Lake Vikjordvatnet. Still, when the correlation coefficients are compared with the visual assessment of covariation in Fig. 5, the picture is somewhat ambiguous. This may be the result of data quality issues or concerns over the suitability of such quantitative analyses for this purpose. One might tentatively suggest the results point in the direct of event-based covariation rather than dead-on trend correspondence. Similar findings have been reported in a recent review of human responses to climate variability during the south Norwegian Mesolithic (Breivik et al., 2017), as well as by similar statistical tests (Shennan et al., 2013, p. 6). While breaking the time series into shorter intervals did produce significant correlations at the event level, the reliability of these results is unknown and would require further investigative efforts to be assessed. They are therefore not reported here.

A special case was made of the near-coast Malangen Fjord core as the visual comparison seemed to suggest remarkable trend correspondence with the local SPD (western coastal sites). Of most interest is the time segment of 6500-2000 cal BP, exhibiting significant negative correlation with the total area SPD, while simultaneously being positively

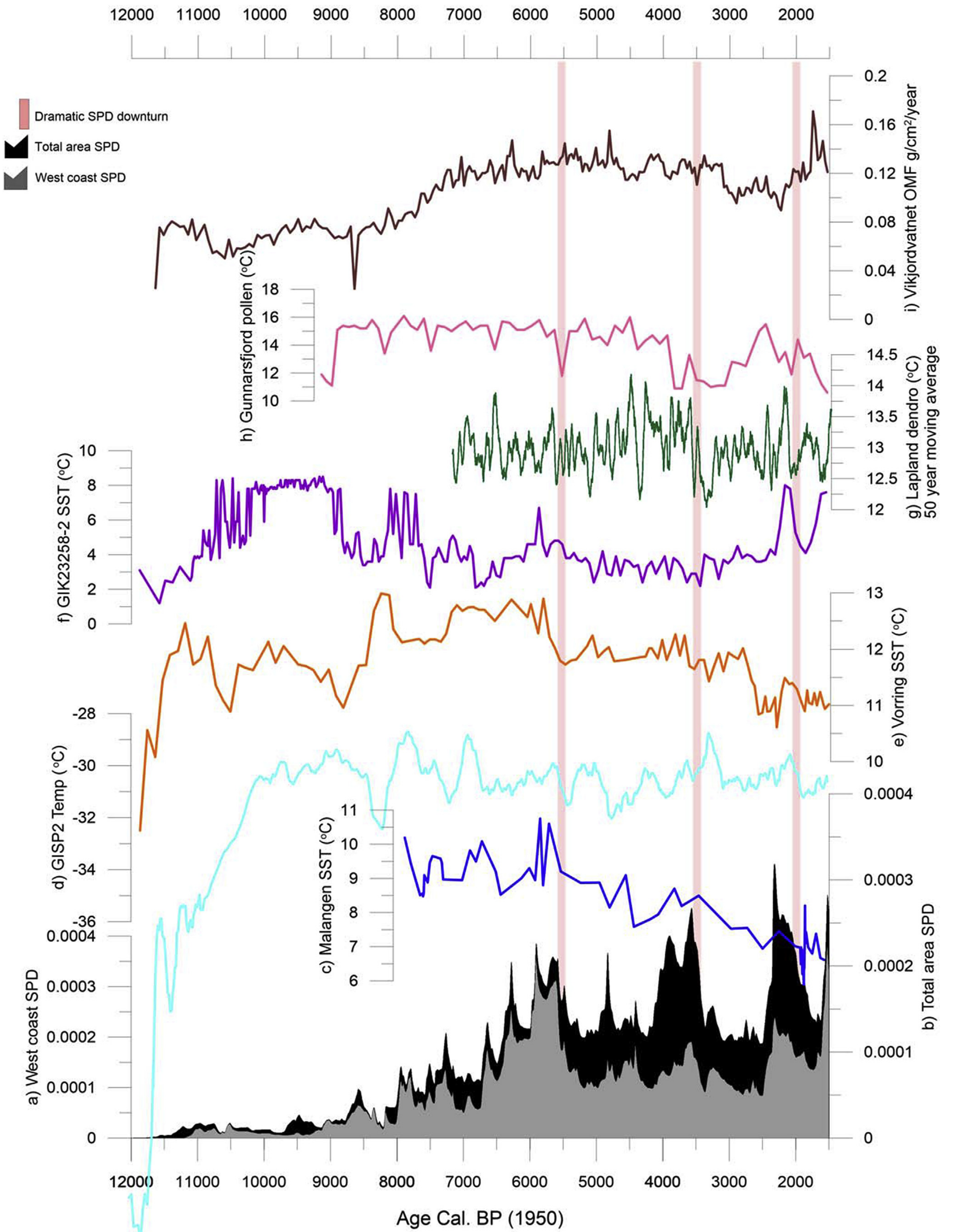

Fig. 5. Multiplot of SPD's and palaeoenvironmental data. Total area SPD (N_{binned} = 857). West coast SPD (N_{binned} = 503).

Table 1
Climate proxies used for comparison and correlation testing.

No.	Site	General location	Lat (°)	Lon (°)	Elev (m)	Source	Proxy	Resolution mean (yr)	Citation
1	Malangenfjord (JM98-1-PC)	N Norway	69.5	18.4	−213	marine	d18O.foram	185	Husum and Hald 2004
2	N. Atlantic shelf break (MD95-2011, JM997-948/2A BC)	Norwegian Sea	67.0	7.6	−1048	marine	alkenones, diatoms, forams, d18O.foram	15	Calvo et al., 2002
3	High N. Atlantic shelf break (GIK23258-2)	Barents Sea	75.0	14.0	−1768	marine	d18O.foram, forams.pl	35	Sarnthein et al., 2003
4	Lapland dendroclimatology	N Fennoscandia	69.0	25.0	N/A	tree	width	1	Helama et al., 2010
5	Over Gunnarsfjorden	N Norway	71.0	28.2	78	lake	pollen	89	Allen et al., 2007
6	Vikjordavatnet	N Norway	68.2	14.1	23	lake	OM.flux	42	Balascio and Bradley 2012
7	GISP2	Greenland	72.6	−38.5	3216	ice	d18O.ice, d18O.ice	31	Alley 2000

Table 2
Correlation results, SPDs vs palaeoenvironmental reconstructions. Total data series, unless otherwise noted.[a]

No.	Site	Proxy	Total area SPD (Exponential smoothing = 0,97)			West coast SPD (Exponential smoothing = 0,97)		
			r	r^2	p-value	r	r^2	p-value
1	Malangen Fjord (JM98-1-PC)	d18O.foram	**−0.528**	0.279	< 0,05	−0.174	0.032	0.149
	Malangen Fjord (JM98-1-PC). Time segment 6500-2000 cal BP		**−0.767**	**0.589**	< 0,05	**0.638**	**0.407**	< 0,05
2	N. Atlantic shelf break (MD95-2011, JM997-948/2A BC)	alkenones, diatoms, forams, d18O.foram	−0.081	0.001	0.390	0.004	0.000	0.966
3	High N. Atlantic shelf break (GIK23258-2)	d18O.foram, forams.pl	−0.496	0.246	< 0,05	−0.465	0.217	< 0,05
4	Lapland dendroclimatology	width	0.109	0.012	< 0,05	0.038	0.001	< 0,05
5	Over Gunnarsfjorden	pollen	−0.318	1.011	< 0,05	−0.147	0.022	0.208
6	Vikjordavatnet	OM.flux	**0.726**	**0.528**	< 0,05	**0.692**	**0.479**	< 0,05
7	GISP2	d18O.ice, d18O.ice	0.404	0.163	< 0,05	0.400	0.160	< 0,05

[a] Bold values reflect particularly interesting results. Threshold arbitrarily set at r = 0.5 and r^2 = 0.4.

correlated with the west coast SPD (see Table 2). This corresponds to the expectation of better fit between local/relevant proxies and local area SPD, and is taken to indicate high relevance of the inner fjord environment to the coastal population. The negative correlation with total area SPD might be explained by inland and eastern adaptations diverging from the western coast.

The strong correlation between both SPD's and Lake Vikjordvatnet OMF is intriguing. As an indicator of bio-productivity, the Vikjordvatnet OMF proxy record tracks changes in both temperature and precipitation – thus making it more informative than a strict temperature reconstruction. The Vikjordvatnet productivity proxy and paleodemographic models show strong trend correspondence leading up to the population peak at 6000 cal BP. Low productivity of the environment may have facilitated population numbers of a correspondingly low magnitude. As productivity increases with the transition to the mid-Holocene (approx. 8000 cal BP), so does the long term population increase set in. This seeming correlation of low environmental productivity resulting in correspondingly low population numbers is also backed by ethnographic data (Binford, 2001; Birdsell, 1958, 1953; Kelly, 2013, p. 178) and similar results from highly comparable palaeodemographic and ecological modelling (Tallavaara and Seppä, 2012; Tremayne and Brown, 2017; Tremayne and Winterhalder, 2017), both support the prediction of direct forcing of population responses to changing bioproductivity.

6.2. Climate/culture comparison

The correlation testing above investigated total data series correspondence. It may also be valuable to look for event-based co-variability. Based on a wide review of the existing palaeoclimate record, climatic events producing signals evident throughout a range of different climate proxies in the area were compared to the three highly significant demographic events:

6.2.1. 2200 cal BP event. Pre-Roman iron age agricultural boom and bust. A pronounced warming event

When reviewing the visual covariation of the 2200 cal BP event and climate proxies in Fig. 5, the event seems to present a strong case of a climate-induced demographic boom and bust-cycle. More or less all proxies testify to a warming event at the time. Both marine and terrestrial proxies substantiate this. Note in particular the remarkable topographic similarities between the total area SPD, dendroclimatology and GIK23258-2, as they share the temporal span and magnitude of the demographic boom and bust–cycle. Many pollen cores from the region testify to boom and bust agricultural activities within a 2–300 year short period corresponding to the 2200 cal BP event (Josefsson et al., 2014; Sjögren and Arntzen, 2013), as do sediment biogeochemical (fecal sterol) data (D'Anjou et al., 2012). In the Lofoten islands “a fairly strong residual D14C excursion occurred between 2340 and 2240 cal a BP, during which the Rystad 1 site experienced dry conditions, manifested in a well-humified peat layer” (Vorren et al., 2012, p. 23). The warm and dry climate conditions resposinble for increased humification is expected to have been conductive to the agricultural expansion. The observed correspondence is therefore in line with palaeodemographic and archaeological expectations.

Still, a large northern European review of pollen, chironomidae and solar forcing data present ambiguous results for the 2200 cal BP event (Seppä et al., 2009, p. 531) - though this might stem from variations in local to regional climate. Climatic conditions conductive to agriculture may have encouraged the subarctic agricultural expansion in northern Norway (cf. Arntzen, 2015). The introduction of iron production technology by Germanic agriculturalists to northern Norway coincides with this event (Jørgensen, 2010, p. 205). Notably, iron production prevailed in the area for only a couple of centuries before disappearing along with a discontinuity in agricultural expansion.

6.2.2. 3500 cal BP event: early Bronze/Metal age downturn. A pronounced cold period

The demographic downturn corresponds to one of the most pronounced cold periods in all of Holocene after the Little Ice Age and the 8.2 event. Dated to 3800-3000 cal BP from a local multi-proxy reconstruction (Seppä et al., 2009, p. 531), the cold period marks the regime shift from warmer, drier conditions in the HCO to colder and wetter conditions, concurrent in a range of climate records from Fennoscandia – pollen, chironomidae, D18O lake sediments and bog surface wetness (Seppä et al., 2009, p. 529). This is backed by a significant and prolonged drop in organic matter flux at Vikjordvatnet and Fiskebølvatnet lakes, Lofoten, N. Norway, corresponding to the 3500 cal BP event and onwards to 2000 cal BP (Balascio and Bradley, 2012). The significance of the 3500 cal BP climate deterioration is highly visible in high resolution dendroclimatology records from both N. Sweden and N. Finland (Grudd et al., 2002; Helama et al., 2013). A dramatic and prolonged cold event co-occurred with the 3500 cal BP demographic trough. Interestingly, there is strong trend correspondence in the total area SPD and dendroclimatology between 4000 and 2000 cal BP. The dendro record stays below pre-3500 cal BP levels until the sharp temperature increase corresponding to the 2200 cal BP event. The climate deterioration is also witnessed in annual laminated lake varves in Lake Sarsjön, N. Sweden, as a horizon with increased mineral deposition dated 3710 ± 86 cal BP, which "is probably associated with the end of the period of relatively stable continental climate recognised in northern Sweden during the Holocene" (Snowball et al., 1999, p. 360). Peat humification data from Lofoten, N. Norway, demonstrate a wet-shift occurring at 3610–3580 cal BP (Sellevollmyra site) and "a marked expansion of Sphagnum between 3600 and 3500 cal a BP, with the Holocene highest percentage of Sphagnum spores during this time window" (Rystad 1 site) (Vorren et al., 2012, p. 23). Cave speleothem from Rana, N. Norway, (core SG93) marks the 4000-3500 cal BP downturn as the most significant temperature drop during its complete Holocene climate record (Lauritzen and Lundberg, 1999, p. 667). Lastly, local glaciers (Lenangsbreene, Lyngen, Troms) start to reform at 3800 cal BP after disappearing at 8800 cal BP (Bakke et al., 2005, p. 536), testifying to the onset of the Neo-glaciation.

Most significantly the 3500 cal BP event coincides with the termination of the intensively investigated Gressbakken-complex in eastern Finnmark (Hood, 2017; Martens et al., 2017). The 3500 cal BP downturn visible in the SPD is observable throughout Troms and Finnmark counties when comparing different areas, suggesting a superregional event. Still, it is significantly more pronounced in the total area SPD – suggesting the influence of the changes occurring outside the area included in the westcoast SPD. It has been suggested that the period entails a move from complex semi-sedentary groups to smaller and mobile units (Myrvoll, 1992, p. 183; Olsen, 1994, p. 131; Schanche, 1994, 1988). The archaeological record is inconclusive beyond indicating the disappearance of the classic Gressbakken house pits (large, deep depression with double hearths and middens) and an end to midden accumulation in eastern Finnmark - but little research has been targeted at post-Gressbakken occupation in east Finnmark.

6.2.3. 6000 cal BP event: twin peaks at terminus HCO. Peaking at 6300 and 5600 cal BP. A pronounced warming event

A summary of 2852 northern European pollen records demonstrate a HCO between 8000 and 5500 cal BP followed by a marked drop in temperature (Seppä et al., 2009, p. 528). The palaeodemographic model reflects this development, with a strongly correlated drop in both data sets at 5500 cal BP. The 6000 cal BP event corresponds to the most significant temperature peak throughout the Holocene. Looking at the proxies in Fig. 5, there is a near uniform trend of particularly high temperatures centering on 6000 cal BP, most significantly in all the marine proxies and the Lake Vikjordvatnet OMF. The terrestrial proxies are rather uneventful at the time, and correspond to the known stable conditions at the. In addition, the local environment seems to be unperturbed by the "global" cold spell produced by Bond Event 4 (5900 cal BP). Peat humification data from Rystad 1, Lofoten, northern Norway, diverge from comparable sites positioned along the North Atlantic Oscillation on the British Isles, in that the interval 6500-5000 cal BP is remarkably stable in N. Norway, i.e. without pronounced wet shifts (Vorren et al., 2012:13). This is in accordance with the very late onset of the HCO in the area, at approx. 6000 cal BP. (Bjune et al., 2004). This corresponds to the demographic 6000-event, and may underline the positive effect of a stable environment on the local human population. The general warming trend leading up to the peak at 6000 cal BP is observable in the High North Atlantic shelf break core, as a steady increase in summer SST from the Holocene low at 6823 cal BP and 2.1 °C to the mid-Holocene high at 5867 cal BP and 6.7 °C. The exceedingly sharp 5500 cal BP demographic downturn is correlated with a marked deterioration in several proxies, most notably in the coastal and marine cores from Malangen and North Atlantic shelf break, but also in terrestrial proxies. Dendroclimatology exhibits a long-term decline between 5600 and 5100 cal BP that corresponds to a marked drop in the Over Gunnarsfjord pollen core. There is also correspondence with the Greenland Ice core for this event. It may also be mentioned that the termination of the peak is concurrent with the Garth tsunami ˜5500 cal BP (Bondevik et al., 2005), though its effects have not been studied or identified in northern Norway yet.

In sum, there seems to be general correspondence (both locally and globally) amongst the climate proxies, indicating stable and productive conditions leading up to the palaeodemographic peak. Furthermore, there is similar correspondence in the abrupt termination of favourable conditions and the demographic downturn at 5500 cal BP. The SPD results strongly indicate the importance of the western coastal environment at the time. Archaeologically, there is an intensified use of ground slate technology (Hesjedal et al., 2009, p. 394, 1996, p. 171) and larger aggregations of habitation structures appear along the western coast (Hesjedal et al., 1996, p. 206). Both are considered testifying to a strong maritime adaptation and specialized exploitation of marine mammals (Hood, 1992:232; Olsen, 1994:69–71).

7. Discussion: climate forcing in the North Atlantic region

So far, the results have been presented without reference to the wider archaeological and demographic context of prehistoric north and west Europe. I now present such a contextualisation and discuss the implication of the results for human ecology studies.

The boom and bust-cycles of the mid-Holocene climate optimum in northern and western Europe is of particular interest in this regard. Multiple studies report highly consistent population dynamics throughout the region during the Neolithic period (Shennan et al., 2013, p. 3; Whitehouse et al., 2014:198), which are usually ascribed to the impacts of an agriculture-induced Neolithic Demographic Transition (cf. Bocquet-Appel, 2011). Interestingly, similar dynamics are also observable in foraging populations in eastern Fennoscandia (Tallavaara and Seppä, 2012, p. 219) and the Baltic region (Warden et al., 2017, p. 6). The areas all have in common a distinct population peak at 6000-5500 cal BP, shared even amongst populations of highly different subsistence strategies and operating under diverse ecological parameters/regimes. The current study of population dynamics in northern Norway also yield a strikingly similar pattern, corroborating the existing pan-European results and further substantiate super-regional climate variability as the primary driver of population dynamics regardless of economic adaptation.

In particular, the recent results of a similar study covering the entirety of the British Isles, presenting an unprecedented data quantity and quality in paleodemographic modelling, gave the remarkable result of boom and bust-cycles equivalent to those of northern Norway: Three mid-to late-Holocene demographic peak and through-events centred on

5800, 4000 and 2200 cal BP (Bevan et al., 2017). The correspondence is surprising, given the large geographical separation (> 20° latitude in variation), different climate settings and the highly variable economic adaptations of the populations in question. Still, the results from the British Isles are quite conclusive regarding the exogenous origin of the forces driving the observable demographic fluctuations: changing climatic regimes (Bevan et al., 2017). Both areas are part of the same large-scale climate system of the North Atlantic region, positioned on the continental/coastal margin, thus the resident populations were likely subject to similar effects of region-wide climate changes. One might still have expected local environmental conditions to be of more importance in structuring the adaptive possibilities and thus governing the local population, than seems to be the case. If these results are correct, they may go a long way to establish large-scale climate variability as the primary driver of prehistoric population dynamics, and crucially, this forcing seems to be the main cause regardless of adaptive strategies, economy, social complexity and/or technological advancement. Although this need not entail a blatant return to eco-determinism, such emerging results (as evident from all over the planet) need to be taken seriously.

It is a well-established and intuitive fact of human ecology that the more energy is available in terrestrial ecosystems the more human consumers can be supported (Kelly et al., 2013; Smith et al., 2008; Tallavaara et al., 2015; Tallavaara and Seppä, 2012; Warden et al., 2017). However, it is also well-established that some maritime environments are highly productive and can support much higher human population densities than adjacent terrestrial environments (cf. Yesner et al., 1980). In the case of northern Norway, the reconstructed sea surface temperature of the Malangen fjord and near-coast OMF from Lake Vikjordvatnet proved significantly correlated with the west coast demographic model. In contrast, the highest resolution proxy – the Finnish dendroclimate data – is not highly covariant. This may be related to issues of proxy temporal resolution and temporal scale commensurability, but likely it is because terrestrial resources and climate patterns were not the key limiting factors for the north Norwegian Stone Age population. Rather, the demographic correlation with the marine/coastal proxies suggests that marine resources were the primary regulator of the human population. Still, marine productivity proxy measures track biochemical compounds of no direct caloric importance to humans, and no true proxy of marine productivity is included in the multi-proxy correlation testing. Nevertheless, it has been thoroughly demonstrated that ocean temperature is an important factor in marine productivity in the environment off the Norwegian coast - though the mechanisms responsible for the input/output-relation are highly complex (cf. Moros et al., 2004; Pathirana et al., 2015; Risebrobakken et al., 2010). Climate/ecology-relations in the local marine environment are nonetheless well-documented through historical correlations between water temperature and recruitment to cod and other fish populations of major prehistoric economic importance (Bogstad et al., 2013; Gjøsæter et al., 2009; Sætersdal and Loeng, 1987). The marine temperature reconstructions may therefore provide useful indicators of marine ecological conditions, when used cautiously.

The direct impact of climate forcing by ocean current variability in northernmost Norway is further demonstrated by a multi-deposit study of lakes positioned along the North Cape Current, providing indicators of coastal climate forcing of terrestrial productivity in their respective coastal zones (Huntley et al., 2013). The terrestrial vegetation responded to variations in the heat transport by the ocean current and indicate that "variations in the strength of the North Cape Current have been of primary importance as the proximal driver of climatic variability in the region since deglaciation" (Huntley et al., 2013, p. 158). This in turn is a response to strength variations in the Atlantic Meridional Overturning Circulation (AMOC) (Huntley et al., 2013:172). Western Finnmark sits at the very northwestern edge of the European continent and marks the boundary between the Norwegian Sea and Barents Sea (Fig. 1). Warm Atlantic waters mix with the cold Arctic waters, and variations in the North Atlantic Current determine the ratio of warmer/colder water masses passing along the coasts of western Finnmark and the extent of the polar front. "Holocene palaeoclimate and ecosystems in this coastal region are thus expected to have been particularly sensitive to variations in the strength of these ocean currents" (Huntley et al., 2013, p. 158). The results strongly suggest the North Cape Current as a primary driver in the local environment and supports the patterns of covariance between the Malangen marine climate reconstruction and the palaeodemographic model. Being exposed and sensitive to these variations, western Finnmark is positioned ideally as an indicator of human adaptation to climate change in the past. The local population had to adapt to an environment on the threshold between two major ocean systems and were therefore subject to both rapid and long term eco-climatic variations.

The findings of Huntley et al. (2013:174) are in general accordance with the results from marine sediment cores regarding the description of ocean current dynamics in the area (Risebrobakken et al., 2011; Ślubowska-Woldengen et al., 2008). Furthermore, fluctuations in the freshwater inflow into the North Atlantic and Arctic Oceans has been proposed as the main mechanism responsible for climate variability in NW Europe (Nesje, 2009, p. 2129; Nesje et al., 2000). A direct link has been demonstrated between the atmospheric responses to variations in the North Atlantic ocean, in which "surface turbulent heat fluxes are indeed driven by the ocean and may force the atmosphere [on timescales longer than 10 years], whereas on shorter timescales the converse is true" (Gulev et al., 2013; cf. McCarthy et al., 2015). Furthermore, studies of Greenland ice cores suggest a strong correlation between sea surface temperature and solar activity – representing a clear case of climate forcing of multi-decadal oscillations ultimately driven by solar insolation (Kobashi et al., 2013; Milankovitch, 1998; Steinhilber et al., 2012; cf. Hays et al., 1976). In short, this is important to the study of palaeodemography and human ecology as the solar energy input provides the basal resource for primary producers and the foundation of any local food chain (photosynthesizing phytoplankton in the marine environment and vegetation in the terrestrial environment), expressed summarily as effective temperature (EF). The causal mechanism connecting climate variability (ultimately driven by solar insolation) and human demography may therefore be more explicitly defined as: *the aggregation of climate effects up through local and relevant food webs, eventually affecting human nutrition and reproduction*.

Case in point, studies connecting climate variability to demographic and economic responses in historic Finland demonstrate the catastrophic effects of the Little Ice Age, Mediterranean volcanic eruptions and variations in growing seasons (Holopainen and Helama, 2009; Huhtamaa and Helama, 2017a, 2017b). Similar historic events are known locally to have had major impact on coastal populations. For instance, Sjögren (2009) suggests that the strong population decline at Sørøya island, western Finnmark, during the 17th century was the result of particularly bad fishing initiated at AD 1627–1629 – potentially due to the Little Ice Age displacing spawning grounds southwards. In addition, positive feedback-loops have been demonstrated between insolation, the shutdown of warm Atlantic water influx and sea-ice formation in the Barents Sea (Semenov et al., 2009). These mechanisms in turn drive the distribution and density of marine resources available for human exploitation, such as fishes and marine mammals. Increased influx of warm and nutrient rich Atlantic water masses has been demonstrated to increase primary productivity, both present and past (Moossen et al., 2013, p. 1708). By implication of the abovementioned historic cases and the human/climate covariation results presented in this paper, the feedback-loops identified by Semenov et al. (2009) should suggest even stronger causal connections between Stone Age demography and marine productivity than for historic farming communities – due to the risk-managing and economic properties of Fennoscandian agrarian populations.

It should be mentioned that some assertions have been made of the highly successful strategies for managing resource-related risk by the historic Sami population in western Finnmark, demonstrating higher environmental resilience than the specialized Norwegian fishing communities (Hansen, 2006). Thus, the generalized and flexible economy of hunter-gatherers may provide adaptive advantages over specialized (e.g. agricultural) economies. Despite these objections, I maintain that results from eastern Fennoscandia clearly demonstrate the potential effectiveness of farming in mitigating environmental risk in the study area, witnessed by the strong inverse correlation between climate and population densities following the advent of farming (Tallavaara and Seppä, 2012, p. 219). The specific causal properties of this apparent relation require further scrutiny.

8. Conclusion

The first palaeodemographic results of a newly assembled north Norwegian radiocarbon database produced three statistically significant demographic peak-and-trough events centred on 6000, 3800 and 2200 cal BP. Multi-proxy correlation testing identified repeated instances of covariation between demographic boom and bust-cycles and environmental conditions.

The human/climate covariation was found to be multifaceted: Comprising long-term trend correspondence with climate proxies of particular economic/ecological importance to the local population, while simultaneously suggesting that the bust-phase of the population cycles were mostly event-based. From a human ecological point of view, this might suggest the importance of distinct climate events that deviate from the dominating conditions and trends – in which more extreme environmental parameters force hunter-gatherer behavioural responses beyond the flexibility of their current adaptive regime. Which may be even more so at higher population densities.

The strongest correlation was obtained between the palaeodemographic model of coastal west Finnmark and regional marine/coastal climate proxies, both on multi-decadal and centennial scales. This is to be expected as the local population exhibit a clear maritime adaptation evidenced by the archaeological record and had to adapt to an environment on the threshold between two major ocean systems. Consequently, the population was subject to both rapid and long term eco-climatic variations caused by the mixing ratio of warm Atlantic and cold Arctic water masses. The results strongly suggest the North Cape Current as a primary driver in the local environment. Being exposed and sensitive to fluctuations in the North Cape Current, western Finnmark is positioned ideally as an indicator of human adaptation to climate changes in the past.

Nevertheless, care must be taken when assigning causal responsibilities in climate forcing of demographic dynamics. Causal linkages need to be demonstrated rather than asserted. Proposed explanations are of limited value without accounting for the aggregation of climate forcing effects up through the locally relevant bio-physical system. Identifying covariation and establishing inter-regional palaeodemography/climate covariation results is but the first step. Despite existing efforts, we are in need of a formal body of causal middle-range theory explaining the generalities and particularities of climate forcing on demography. Consequently, we need to further enhance our knowledge of how the effects of climate variability is aggregated up through the food chain to affect resources relevant to a specific human population. I suggest this is particularly pertinent for the complex interactions in marine environments, as the implications for maritime-adapted human populations are less formalized than those of terrestrial ecosystems.

A limiting factor of the methodology applied here is the implication of treating dynamic population events as a closed system defined by the boundaries of the study area. The mono-causal exploration of human/climate covariation presented here does not undercut the importance of other variables in explaining long-term palaeodemographic trends. This is vital when considering that hunter-gatherer populations mitigate risk through super-regional networks including the flow of genes, calories, technology and information (Bocquet-Appel et al., 2005; F.Riede, 2009a,b; Riede, 2014; Riede et al., 2017). This includes responses to environmental stressors and climate forcing. Future research should integrate multi-national datasets in order to overcome this issue in Fennoscandia at large.

A comparison with regional results demonstrated remarkable similarity in demographic trends with mid-Holocene north and west Europe. The mid-Holocene climate optimum population peak is consistently reported throughout northwestern Europe. The results of the north Norwegian radiocarbon record are thus consistent with independent, international efforts. In combination, they go a long way in establishing large-scale climate variability as the primary driver of prehistoric population dynamics, and crucially, this forcing seems to be the main cause regardless of adaptive strategies, economy, social complexity and/or technological advancement.

Declaration of interest

None.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.quaint.2018.05.014.

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Paper 2

Research Paper

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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

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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

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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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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 socioecological 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)

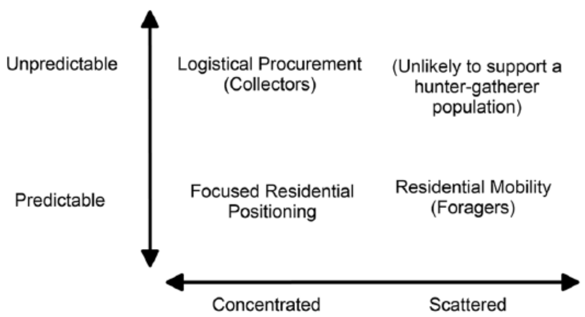

Figure 3. Expected hunter-gatherer mobility strategies in relation to selected resource distribution characteristics. Redrawn from Whallon (2006: 260).

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

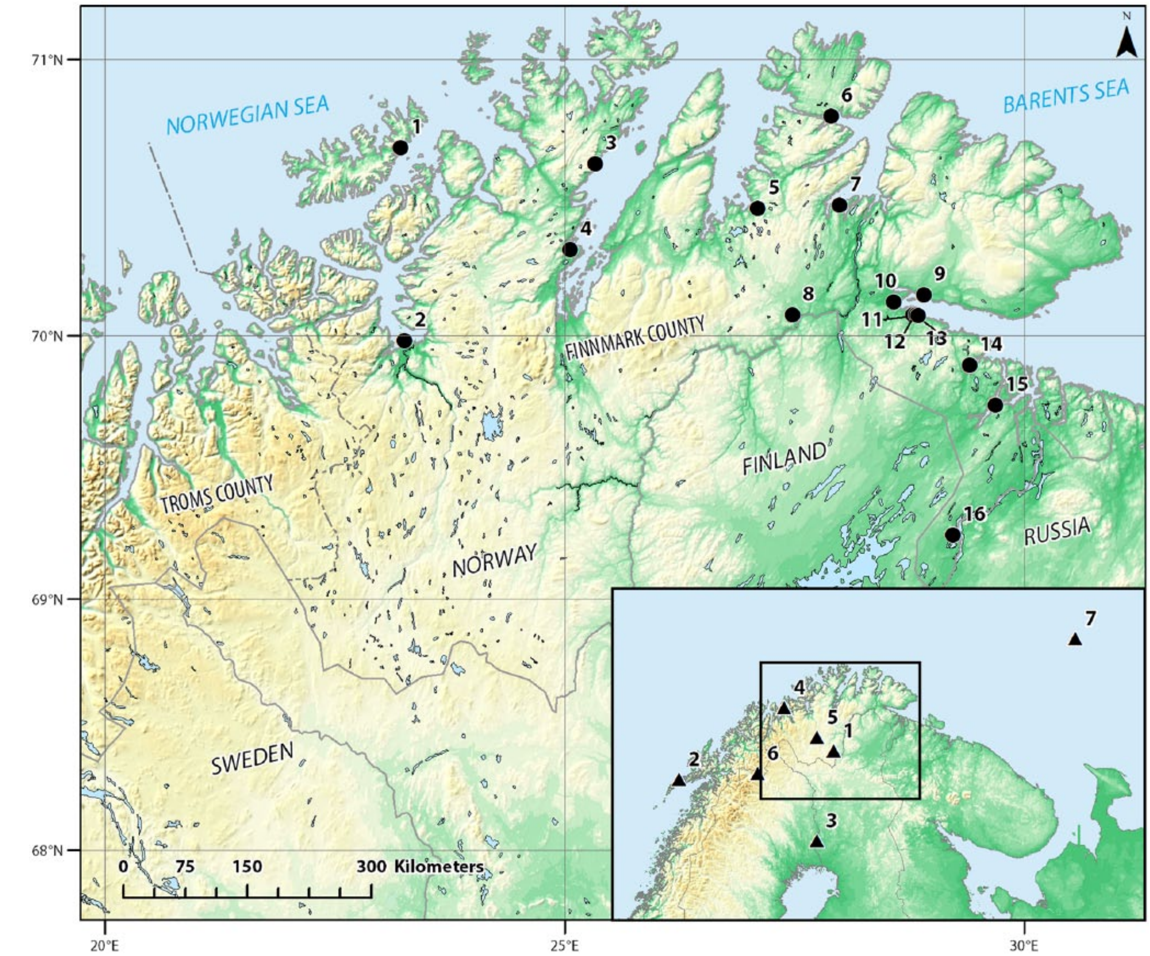

Figure 4. Area map plotting the location of the dated Gressbakken sites, providing data in this paper: 1. Sandbukt, 2. Tollevika, 3. Skarvbergvka, 4. Tverrnes, 5. Leirpollen, 6. Iversfjord, 7. Torhop, 8. Laksjohka, 9. Bergeby, 10. Karlebotn, 11. Advik, 12. Gressbakken, 13. Nyelv, 14. Valen, 15. Kalkkilebukt, 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 ⩽ 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

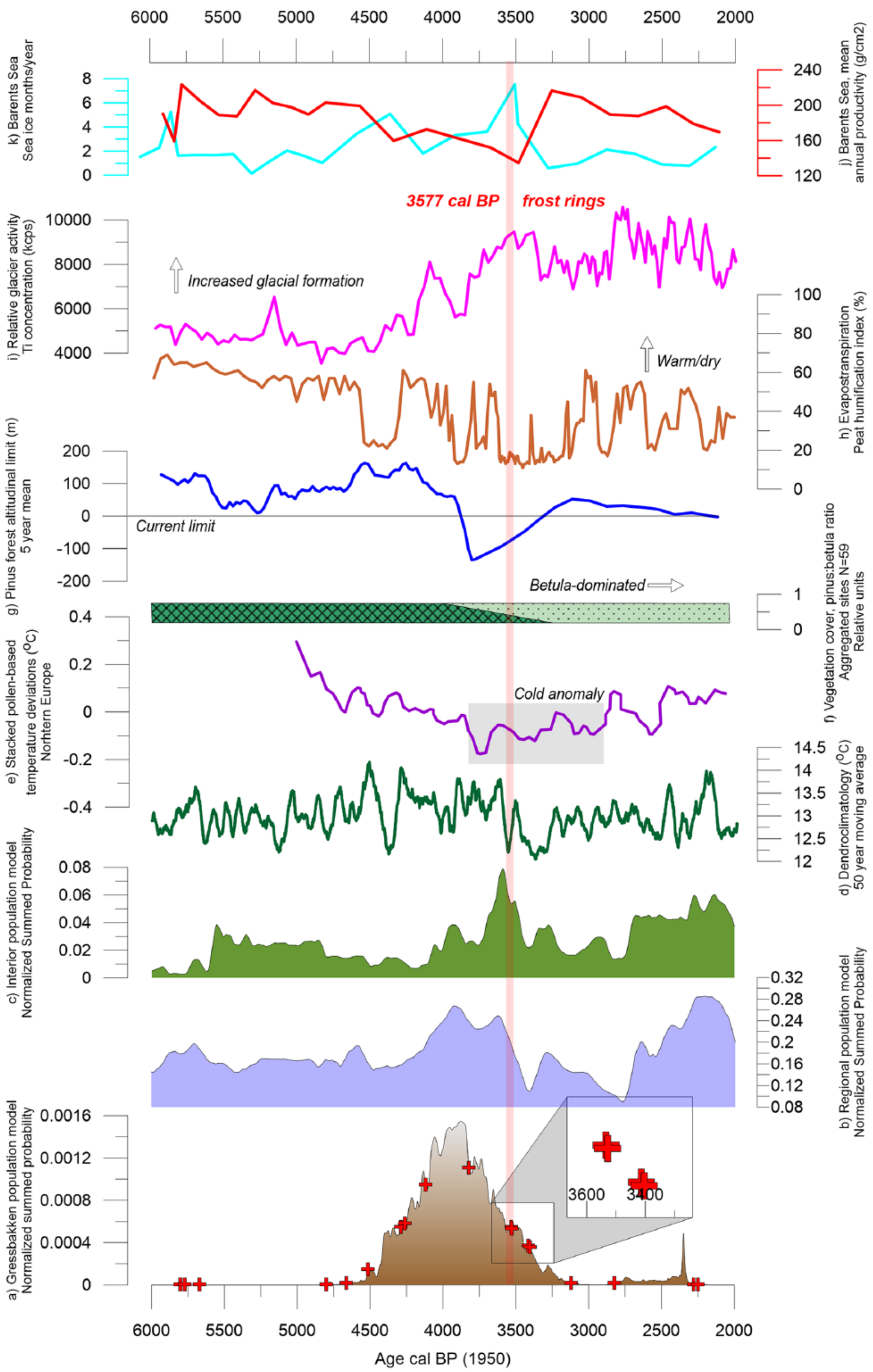

Figure 5. Stacked plots of population models and paleoenvironmental reconstructions. (a) Gressbakken population model, normalized summed probability. (b) Regional population model, normalized summed probability. (c) Interior population model, normalized summed probability. (d) Dendroclimatology (°C), 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.

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Supplementary material

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

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Paper 3

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Climatic changes cause synchronous population dynamics and adaptive strategies among coastal hunter-gatherers in Holocene northern Europe

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Abstract

Synchronized demographic and behavioral patterns among distinct populations is a well-known, natural phenomenon. Intriguingly, similar patterns of synchrony occur among prehistoric human populations. However, the drivers of synchronous human ecodynamics are not well understood. Addressing this issue, we review the role of environmental variability in causing human demographic and adaptive responses. As a case study, we explore human ecodynamics of coastal hunter-gatherers in Holocene northern Europe, comparing population, economic, and environmental dynamics in two separate areas (northern Norway and western Finland). Population trends are reconstructed using temporal frequency distributions of radiocarbon-dated and shoreline-dated archaeological sites. These are correlated to regional environmental proxies and proxies for maritime resource use. The results demonstrate remarkably synchronous patterns across population trajectories, marine resource exploitation, settlement pattern, and technological responses. Crucially, the population dynamics strongly correspond to significant environmental changes. We evaluate competing hypotheses and suggest that the synchrony stems from similar responses to shared environmental variability. We take this to be a prehistoric human example of the "Moran effect," positing similar responses of geographically distinct populations to shared environmental drivers. The results imply that intensified economies and social interaction networks have limited impact on long-term hunter-gatherer population trajectories beyond what is already proscribed by environmental drivers.

Keywords: Synchronicity; Moran effect; Human ecodynamics; Hunter-gatherers; Paleodemography; Maritime adaptation; Fennoscandia

INTRODUCTION

Synchronized demographic and behavioral patterns among distinct and geographically separate populations is a well-known natural phenomenon that has been demonstrated across animal and plant populations. The study of spatial synchrony has thus become a key topic in population ecology. "Spatial synchrony" refers to coincident changes in the abundance or adaptive response of geographically disjunct populations (Liebhold et al., 2004). Three primary mechanisms have been offered to explain such synchrony: (1) dispersal or migration among populations, (2) trophic interactions with populations of other species that are themselves spatially synchronous or mobile, and (3) spatially correlated environmental influences (Liebhold et al., 2004). This last phenomenon, known as the "Moran effect," reflects upon the tendency of spatially separated populations to fluctuate in synchrony when exposed to similar environmental conditions (Moran, 1953). The Moran effect is often thought to be the result of synchronous weather or climate influences acting on spatially disjunct populations (Moran, 1953; Koenig, 2002; Rosenstock et al., 2011; Kahilainen et al., 2018).

For prehistoric humans, Shennan et al. (2013) were the first to identify synchrony in ^{14}C date-based human population proxies across mid-Holocene Europe. This synchrony was attributed to migration and population growth, induced by the introduction of agriculture 8000–6000 cal yr BP. Recently, Freeman et al. (2018) argued that synchronous patterns in ^{14}C time series observed across the globe during the

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Holocene were the result of intensified networks of trade and migration within continents, while convergent cultural evolution toward more energy-consuming political economies with higher carrying capacities account for global synchrony. However, as Freeman et al. (2018) admit, they omit climate change as the driving force behind the observed synchrony, despite it being the explanation most commonly used in ecology. This is critical, as climate can influence human growth rates either directly (extreme events) or indirectly by affecting environmental productivity and, consequently, food availability. We suggest that evaluating the role of climate change in driving synchronous human demographic and adaptive responses requires analyses sensitive to regionally specific ecological conditions.

Here, we compare Holocene hunter-gatherer ecodynamics in two northern European regions: western Finland and northern Norway. We investigate the role of climate in controlling coastal hunter-gatherer population trends and changes in adaptive strategies between the two regions. We show that population size and adaptive strategies change synchronously between western Finland and northern Norway. These changes coincide with climate changes and consequent changes in food availability. Thus, our results highlight the role of environmental factors in creating spatial synchrony in long-term human population dynamics across space.

REGIONAL SETTING

The data catchment areas of our study are the coasts of northern Troms and western Finnmark Counties, constituting the northwesternmost margin of Norway (69°–71° latitude), and the Ostrobothnian coast in western-central Finland (63°–65° latitude) (Fig. 1).

The study areas occupy northern coastal ecotones while simultaneously being different systems in terms of ecology and geography. These areas are positioned along different aquatic systems: northern Norway is on the oceanic interface of the North Atlantic and the Barents Sea, where upwelling, salinity, and significant tidal actions produce a highly productive coast. Western Finland is adjacent to the more enclosed Gulf of Bothnia in the Baltic Sea, marked by relatively low salinity and minimal tides. Also, the topography of these areas differ: western Finland is a flat continuous coastline, while northern Norway is a rugged, mountainous coastline scattered with islands and deep-cutting fjords.

By the time of the mid-Holocene, the two areas had quite different ecological systems. The Finnish area has a significantly more productive terrestrial ecosystem compared with that of northern Norway, primarily due to latitudinal differences. Major changes occurred in the terrestrial environment during the mid-Holocene, as the previously species-rich mixed forest of the Finnish terrestrial system became increasingly dominated by spruce (*Picea abies*). This turned the forest ecosystem into a modern boreal taiga dominated by spruce (*Picea abies*) and pine (*Pinus sylvestris*) (Seppä et al., 2009a).

A recent compilation of a large set of pollen cores from across northern Norway indicates a patchwork of vegetation cover, structured by both the inland/coast axis and the west/east axis, in which the outer coastal area of northwestern Norway was characterized by birch (*Betula*) forest cover exceeding current conditions (Sjögren and Damm, 2019). This likely impacted the biogeography of key terrestrial mammals with a shift from postglacial large herds of migratory ecotype reindeer (*Rangifer tarandus*) to smaller herds of sedentary ecotype reindeer (*R. tarandus*) (Hood, in press, p.23).

Another important factor in area selection is the fact that Fennoscandia hosts archaeological records of continuous hunter-gatherer populations throughout the Holocene. These records demonstrate shared adaptive characteristics between the areas with reliance on marine subsistence technologies at an early stage. What is more, there are some indications of participation in extensive interaction spheres, as evidenced by shared material culture traits such as slate technology, ceramics, rock art, imported amber, and early metal products (Damm, 2006; Nordqvist et al., 2012; Ramstad et al., 2015). However, very little evidence exists to determine the magnitude of interaction between the areas. The assumed connections must therefore be seen as highly tentative, and we stress that there is more evidence indicating separate rather than shared culture-history in these areas.

The areas have some similarities in postglacial colonization history, but also exhibit important differences. Following the deglaciation of the final Pleistocene, coastal areas of the Fennoscandian/Baltic shield became increasingly accessible for colonization by marine flora and faunas. This process is thought to have triggered a significant incentive for humans to colonize the postglacial coastal landscape of northernmost Europe. This entailed a radical economic shift: From terrestrially oriented foraging societies of the late-glacial Ahrensburgian and Butovo/Veretye groups on the Eurasian plain, moving north and west and developing the maritime adaptations quintessential to the Scandinavian Mesolithic (Schmitt et al., 2006; Bang-Andersen, 2012, 2013; Schmitt, 2015; Schmitt and Svedhage, 2015; Dolukhanov et al., 2017). The colonization of Norway at the termination of the Younger Dryas (11,700 cal yr BP) occurred along a coastal route requiring seafaring vessels and the know-how of a marine-oriented economy (Bjerck, 2017). The case is somewhat different in Finland, which was colonized via a terrestrial route. The Finnish case is most in line with the model suggesting maritime adaptations originated in Upper Paleolithic river resource utilization and were later adapted to larger water bodies, allowing people to move into the marine niche on the oceanic coasts (Vasil'evskii et al., 1998; see also; Cziesla, 2007, 2018; Terberger et al., 2013). At the Pleistocene/Holocene transition, most of present-day Finland was submerged due to glacio-isostatic loading, yet the ensuing isostatic uplift rapidly transformed the area from a postglacial coast into a patchwork of rivers, lakes, and wetlands. The archaeological record also testifies to aquatic economies from the very onset. Complex technologies used for aquatic resource exploitation are evident already from the early Holocene, including the spectacularly well-preserved Antrean fishnet dated to 10,500 cal yr BP. During the mid-Holocene, massive

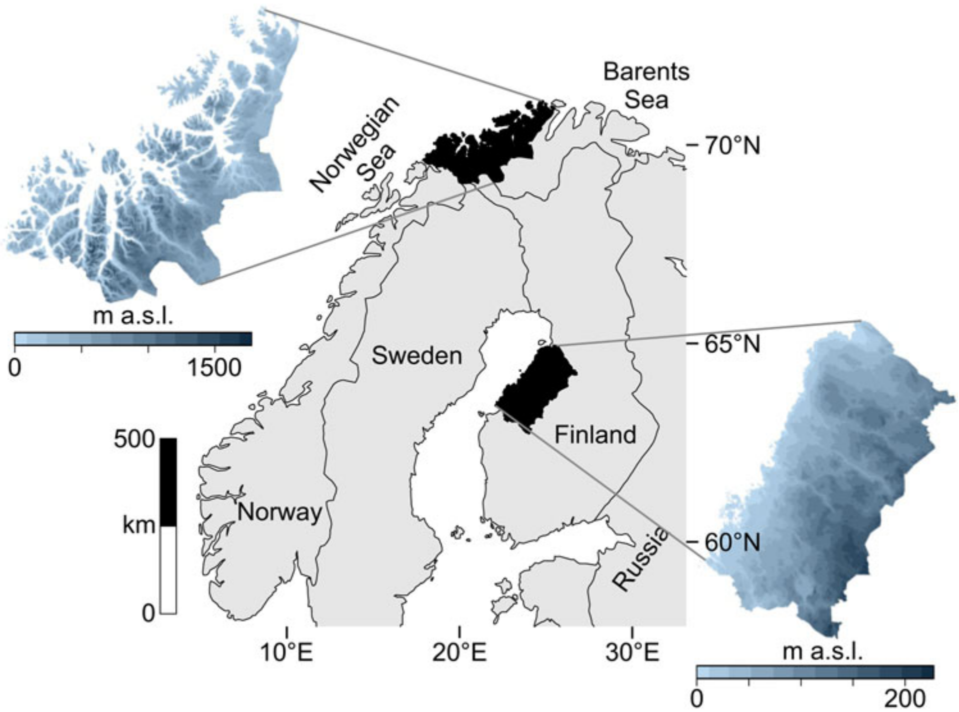

Figure 1. (color online) Map of the two study regions within northern Europe.

stationary fishing structures, such as weirs and lath screen traps recovered from multiple estuaries, offer extensive evidence of marine-oriented facilities requiring substantial investment (Koivisto, 2012; Koivisto and Nurminen, 2015; Butler et al., 2019; Groß et al., 2018; Koivisto et al., 2018). The different routes to maritime adaptations underline the comparative relevance of the cases and provide pertinent insight into the evolution of full-fledged maritime adaptations.

Data quality is also a vital factor in area selection. Both areas have been intensively investigated archaeologically, including large-scale excavations and surveys. Together with excellent paleoenvironmental records, the two regions offer robust testing grounds for evaluating changing human ecodynamics.

MATERIALS AND METHODS

Human population size proxies

We reconstruct human population trends in the two areas using temporal frequency distributions of archaeological materials. We consider the time span from the early Holocene colonization at ~12,000 cal yr BP to about 2000 cal yr BP, at which point farming achieved a more permanent foothold and changes in settlement patterns and economy ensued in northern Fennoscandia. Before this, farming made minimal impact on both areas, particularly in northern Norway.

For western Finland, we use the temporal distribution of 754 shoreline-dated sites as the basis of the population reconstruction (Tallavaara and Pesonen, 2018). A gradual and well-established shoreline displacement due to postglacial isostatic uplift provides high-resolution dating on the basis of elevation above sea level. As with radiocarbon dates, we assume that variation in the number of sites reflects relative changes in past population size. The sites have primarily been identified through LiDAR mapping, and the current sample exclusively consists of sites positively confirmed as archaeological remains by field surveys. Included site types range from open-air sites to pithouse sites of variable sizes to row-house sites and megastructures. Despite a potentially lower chronological resolution, we argue that this approach is justifiable, as it substantially boosts sample size in an area containing few radiocarbon-dated sites. Further, the approach helps overcome investigation biases, as all identifiable site types are included regardless of the presence of radiocarbon dates. Thus, this site-based proxy sidesteps many of the sampling biases inherent in radiocarbon-based population proxies. This approach also takes advantage of the favorable isostatic properties of the area. Western Finland is positioned near the weight center of the Fennoscandian ice cap, resulting in isostatic uplift of more than 200 m over the past 12,000 yr. Given a mostly flat topography, the isostatic rebound of the area provides ideal conditions for high-resolution shoreline dating. Virtually identical trends have been established between the regional site-based reconstruction and the summed probability distribution (SPD), which is based on radiocarbon dates covering the total area of Finland (Tallavaara and Pesonen, 2018). This strengthens the reliability of the site-based proxy.

For northern Norway, the reconstruction of population dynamics is based on the SPD method of radiocarbon-dated site-occupation events (Shennan and Edinborough, 2007;

Williams, 2012; cf. Ramsey, 2017). This method is premised on the proportional relation between population size and datable components of the archaeological record (Rick, 1987; see Haynes, 1969; Kirch, 1980). This so-called dates-as-data premise implies that smaller populations leave behind a smaller sample of archaeologically visible traces compared with larger populations. Major efforts have been made to test this premise (Surovell and Brantingham, 2007; Surovell et al., 2009; Shennan, 2013; Timpson et al., 2014). Following the results in Edinborough et al. (2017), the method has demonstrated its usefulness in reconstructing paleodemographic fluctuations. For the current study, archaeological radiocarbon dates were collected for the coast of northwestern Norway, which contains the densest and most recently produced radiocarbon record in northern Norway. The data set (N = 735) exclusively comprises radiocarbon dates from secure archaeological contexts, made on terrestrial carbon (data set available at: https://dataverse.no/dataset.xhtml?persistentId=doi:10.18710/AV9R5X). These have been further vetted for taphonomic, investigative, and sampling biases (Jørgensen, 2018). The dates were then structured into 503 bins of 200 yr to control for overrepresentation of more intensively investigated sites. Further details on auditing measures of the current data set are presented in Jørgensen (2018). Although the population proxies for our two study areas are derived from different source data, we have opted for this strategy, as it produced samples of comparable size.

Paleoenvironmental data

Holocene environmental changes are represented by eight paleoecological and paleoclimatic proxies. We selected available proxies related to the productivity of terrestrial and marine environments and, consequently, to food availability for hunter-gatherers. Somewhat different environmental proxy types represent the two areas. This is the result of regional differences in depositional and geomorphic qualities, as well as unequal conditions for preservation of paleoenvironmental proxy data. The paleoenvironmental proxies discussed in this paper are summarized in Table 1.

Prehistoric human population dynamics in western Finland are compared with: (1) a measure of annual mean temperature, which is a stack of four pollen-based temperature reconstructions across southern and central Finland; (2) the strength and length of the growing season, which is based on organic matter flux in a varved lake (Ojala and Alenius, 2005; Ojala et al., 2008); (3) Baltic Sea surface temperature (SST) reconstruction, derived from TEX86-paleothermometer measurements (Warden et al., 2017); and (4) Baltic Sea salinity levels (‰) based on the compilation of several proxies (Gustafsson and Westman, 2002). Salinity is important in tracking changes in oceanic versus the enclosed, brackish conditions of the Baltic Sea. This has ecological implications, as salinity levels structure aquatic biogeography and affect the productivity of the Baltic Sea.

For northern Norway, the SST of the North Atlantic Current collected at the offshore shelf break tracks variation in mixing of warm Atlantic and cold Arctic waters at the mid-Norwegian margin (Calvo et al., 2002). Ocean mixing is a significant factor in structuring marine biogeography and for inferring large-scale oceanographic and environmental conditions. Two proxies of inner coastal aquatic conditions in northern Norway are included, as the fjord biome is of great importance to the human populations in the area. Bottom water temperatures (BWT) of a major fjord system (Malangen fjord) in the study area track changes in the coastal current (Husum and Hald, 2004). In addition, we contribute a new paleoproductivity measure of the same local fjord environment. The fjord productivity proxy is made up of previously unpublished data, courtesy of Jochen Knies at the Norwegian Geological Survey. The percentage of carbonate is used as a direct marker of productivity in the fjord as it relates to the abundance of calcium/chalk-dependent zooplankton, which in turn is the foundation of the marine trophic pyramid. This assumption is justified, as the relative proportion of terrigenous-free (biogenic) carbonate has been shown to be a highly suitable indicator of changes in paleoproductivity in the area (Knies et al., 2003, pp. 1–2; cf. Gardner et al., 1997).

We also include a humification index from the outermost western coast of Norway. The peat humification index is a combined indicator of temperature and precipitation—evapotranspiration—that also reflects changes in terrestrial productivity (Vorren et al., 2012).

Maritime resource exploitation data

To explore potential synchrony between adaptive strategies, population size, and environment, we assembled multiple indicators of marine resource use.

To track changes in the subsistence/adaptive strategies in western Finland, we calculate two closely related measures: the proportion of seal bones in archaeofaunal assemblages in coastal sites (seal NISP (Number of Identified Specimens)/total NISP) and the index of seal bones relative to terrestrial mammals (seal NISP/(seal NISP + terrestrial mammal NISP)) (Grayson, 1984). Although not a direct quantitative measure of seal consumption, we assume that changes in the proportion of seal bones reflect changes in the importance of seals in human diet. As a secondary premise, we assume that such variation indirectly reflects adaptive adjustments following either environmental or technological changes. The archaeofaunal data consist of 37,810 burnt bone fragments from 72 archaeological assemblages across the Finnish coast. These data were extracted from the archives of osteological reports compiled by Pirkko Ukkonen and Kristiina Mannermaa at the Finnish Museum of Natural History and from osteological reports at the National Board of Antiquities. The faunal record was attributed to broad chronological periods based on time constraints given by associated radiocarbon dates or typological artifact attribution: Early Mesolithic (11,000–8500 cal yr BP), Late Mesolithic (8500–7200 cal yr BP), Early Sub-Neolithic (7200–6000 cal yr BP), Middle

Table 1. Climate records employed for paleoenvironmental review.

No.	Site	Tracks[a]	Latitude (°N)	Longitude (°E)	Elevation (m)	Source	Proxy	Function in climate review	Citation
	Finland								
1	Lakes Arapisto, Kuivajärvi, Laihalampi and Nautajärvi	Annual mean temperature	61.3	26.0	136.6	Lake	Pollen, multiple combined	Four pollen-based temperature reconstructions stacked into a mean annual temperature for the Finnish boreal zone	Heikkkilä and Seppä, 2003; Sarmaja-Korjonen and Seppä, 2007; Ojala et al., 2008; Seppä et al., 2009b
2	Lake Nautajärvi	Growing season intensity	61.5	24.4	103.7	Lake	Organic matter flux, varved lake	Provides a measure of the environmental growth potential, tracking strength and length of primary production season	Ojala and Alenius, 2005; Ojala et al., 2008
3	Baltic Sea (core 303600)	Baltic SST	56.6	19.2	−175	Marine	TEX86, thaumarchaeotal membrane lipids	SST of the Baltic Sea	Warden et al., 2017
4	Baltic Sea, multiple sites	Baltic salinity	—	—	—	Marine	Salinity, $\delta^{18}O$, molluscan fauna	Tracks changes in oceanic vs. enclosed, brackish conditions; important for structuring the aquatic biogeography as salinity affects productivity	Gustafsson and Westman, 2002
						Marine			
	Norway					Marine			
5	N. Atlantic shelf break (MD95-2011, JM997-948/2A BC)	North Atlantic Current SST	66.58	7.38	−1048	Marine	Alkenones, diatoms, forams, $\delta^{18}O$.foram	U37K-derived SST of the North Atlantic Current tracking variations in admixture of warm Atlantic and cold Arctic waters at the mid-Norwegian margin	Calvo et al., 2002
6	Fjord Malangen (JM98-1-PC)	Fjord BWT	69.5	18.4	−213	Marine	$\delta^{18}O$.foram	BWT of inner fjord marine core; tracks changes in the coastal current	Husum and Hald, 2004
7	Fjord Malangen (JM98)	Fjord productivity	69.5	18.4	−213	Marine	Forams, carbonate %	Paleoproductivity measure of the local fjord environment	Knies (previously unpublished)
8	Rystad 1	Effective evapostranspiration	68.24	13.78	40	Peat	humification index, colorimetric	Indicator of temperature and precipitation combined — evapotranspiration — on the outermost western coast	Vorren et al., 2012

[a]BWT, bottom water temperature; SST, sea-surface temperature.

Sub-Neolithic (6000–5400 cal yr BP), and Late Sub-Neolithic (5400–3500 cal yr BP).

Due to poor preservation of organic remains, there is no representative archaeofaunal sample to draw on from the Norwegian area, and we had to devise an alternative measure of marine resource use. To map changes in marine resource use, we assembled a "slate index," premised on the strong affinity between maritime adaptive strategies and the use of slate tools. The slate index tracks the abundance of slate tools relative to other lithic industries, based on the averaged frequencies of slate versus cryptocrystalline lithic materials from a selection of reliably dated site assemblages. The data set consists of 37 securely dated lithic assemblages covering the entire local Stone Age chronology, with more than 22,000 lithic objects. Importantly, most of the assemblages stem from multiphase sites of significant occupation history. This factor helps control for variation in site function. As the ecological properties of a single coastal site are assumed to be more or less stable, any major variation in lithic assemblage composition through time is assumed to reflect changes in subsistence strategies.

Based on the near-universal reliance on slate tools among circumpolar maritime hunter-gatherers (Fitzhugh, 1974), we assume that slate tools provide a reliable indication of maritime resource exploitation. There have been multiple attempts at explaining the strong prevalence and assumed superiority of slate tools for maritime economic purposes (Gjessing, 1953; Dumond, 1968; Ritchie, 1969; Fitzhugh, 1974; Clark, 1980, 1982; Morin, 2004; Graesch, 2007; Dinwiddie, 2014). As a basic premise, we follow several arguments and empirical demonstrations (Clark, 1979; Wilhelmsson, 1996; Nuñez, 1998; Morin, 2004) that slate technologies can reduce handling costs and facilitating mass harvesting of marine resources (sensu Madsen and Schmitt, 1998), and thus alter the energy budget and ranking of marine/terrestrial resources. As a result, slate technology could significantly boost food security and survivorship, and hence population numbers, among maritime hunter-gatherers. In northern Norway, slate tools have an almost exclusively coastal distribution, supporting our assumption that slate tools were used primarily as a maritime technology and thus are a relevant proxy for marine resource exploitation. Despite lower sampling density of inland sites potentially contributing to this picture, a review of existing data suggests two patterns: (1) There is literally no evidence for slate tool production in the interior, indicating import (Hood, 1992, p. 521). (2) In the rare cases of locally procured material, inland slate tools appear to be of a much more silicified raw material and subject to a different reduction sequence, occasionally even made by recycling greenstone tools (see Rigajokka site [Helskog, 1974, pp. 4–5]) — thus not really slate at all.

RESULTS

Figure 2 shows the reconstructed population dynamics/trajectories for northern Norway and western Finland and reveals a clearly synchronous pattern between the two regions. A major feature in both reconstructions is the prominent boom-and-bust cycle between 6500/6000 and 5000 cal yr BP. However, in northern Norway the highest population levels apparently occur ca. 300 yr earlier than in western Finland. In addition to this major population boom-and-bust, the population proxies further indicate minor, synchronous declines at 8200 and 7000 cal yr BP.

Figure 3 further shows a correspondence between long-term human population dynamics and environmental variability in both areas. In the Finnish data set, proxies covering both marine and terrestrial productivity show increasing trends culminating around 6000 cal yr BP, concurrent with the prominent population peak (Fig. 3b–e). This is particularly evident in the marked correspondence between the reconstructed population trend, growing season intensity (Fig. 3c), and the Baltic Sea SST (Fig. 3d). The subsequent population decline coincides with declining late Holocene productivity (see also Tallavaara and Seppä, 2012). Furthermore, population dips observed in both areas at around 8200 and 7000 cal yr BP coincide with shorter-duration downturns in temperature and growing season intensity (Fig. 3b–d).

The pattern is similar in the Norwegian study area, where marine proxies (Fig. 3i–k) show peaking SSTs and marine productivity around 6000 cal yr BP. The North Atlantic Current conveyed higher quantities of warm Atlantic water during the mid-Holocene and the coastal water temperature and marine productivity peaked in the major fjord system within the study area (Fig. 3i). This indicates a mild climate with increased Atlantic water in the fjord system that drove the production of carbonate (either produced in situ or transported with the Atlantic water).

In accordance with the Finnish data, temperatures and productivity declined after 6000 cal yr BP. The evapotranspiration reconstruction (Fig. 3h) shows a slightly different pattern, as the highest values occur between 7500 and 6500 cal yr BP. Nevertheless, very stable conditions are recorded around the 6000 cal yr BP population peak, while a general climate shift toward highly variable conditions occurred with the transition to the late Holocene.

In northern Norway, the population decline at 8200 cal yr BP coincide with the Storegga tsunami, caused by the massive submarine landslide in the Norwegian Sea (Romundset and Bondevik, 2011). Furthermore, the 7000 cal BP downturn corresponds to the Tapes transgression (Sørensen et al., 1987; Romundset et al., 2011). Thus, taphonomic loss of archaeological material may be responsible for the declines in the Norwegian population proxy (see also Jørgensen, 2018, 5). However, this is most likely an insufficient cause, as the population declines at 8200 and 7000 cal yr BP perfectly mirror the Finnish settlement data, in which no such taphonomic loss is observed. This suggests that these specific declines in northern Norway most likely are actual demographic events. Although low amplitude, these apparent population dips correspond to a hiatus in settlement sites in Finland and reduced site numbers in Norway.

Considering the precise synchrony of these events between western Finland and northern Norway, it is of interest that the

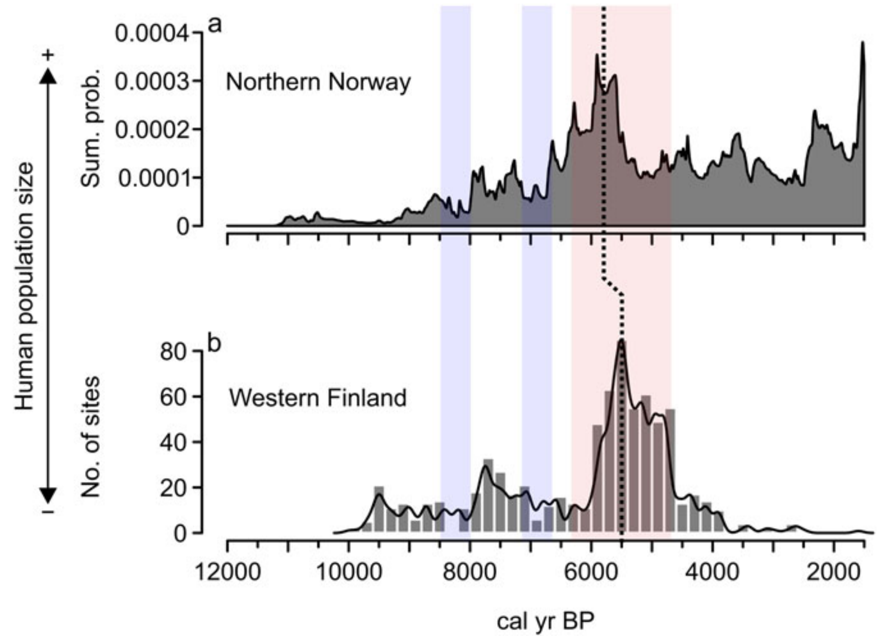

Figure 2. Comparative figure of reconstructed population trends of the two areas. Blue bars mark synchronous, negative fluctuations. Red bar marks synchronous, positive fluctuation. Dotted, vertical line illustrates the lag in timing of the most significant population cycle between the areas. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

main population event appears to occur slightly earlier in northern Norway, with a more gradual buildup and more abrupt collapse compared with the Finnish population cycle. The slight variation in dating of these events may be the result of the methods used to reconstruct population dynamics. This has been indicated previously, as a similar age shift in the highest population levels between different population proxies has been observed in the Finnish data (Tallavaara and Pesonen, 2018). Another possibility is that the timing of the main population cycle corresponds to different timings of the most favorable environmental conditions in the separate areas. This is supported by the identification of a latitudinal gradient in the timing and duration of the peak Holocene thermal maximum occurring earlier in the higher latitudes of Fennoscandia (Eldevik et al., 2014, p. 228). Future efforts should aim at discriminating between methodological and climatic effects in explaining this lag, as well as further issues of data resolution.

In addition to the correspondence between population and environmental proxies, proxies indicating marine resource use also correlate with population and environmental proxies in both areas. Marine resource use increases along with increasing population size and environmental productivity until around 6000 cal yr BP and declines as population size and productivity proxies decrease. The Finnish archaeofaunal record (Fig. 3f) shows that during the boom phase of the mid-Holocene population event, seal bones make up more than 70% of the coastal archaeofaunal assemblages. The trend of seal exploitation intensity corresponds to both the growth and decline phases of the population trajectory.

In Norway, the use of slate intensified from 7000 cal yr BP and became the dominant lithic industry by the time of the population peak (Fig. 3l). By this time, slate concentrations often constituted as much as 80% of coastal assemblages. We assume that this reflects a change in adaptive strategies toward more intensified use of marine resources in the region. A shift away from slate in favor of a more expedient technology based on local quartz occurred simultaneous with the population decline. Slate was still important for some time after the 5500 cal yr BP population decline, but the slate component is reduced from 70%–80% to about 30%. In addition to the slate index, several other characteristics of the Norwegian archaeological record support the idea of increased marine resource use during the population boom. From 7000 cal yr BP, larger coastal sites consisting of multiple pit houses emerge. Despite there being some indications of pit-house construction occurring before this period, this represented a marked change in settlement longevity (Damm et al., 2019; Gjerde and Skandfer, 2018), indicating increased locational investment in coastal sites and a shift in coastal settlement pattern and organization. Furthermore, recent investigations of differences in coast and inland human presence clearly demonstrate an almost complete lack of inland occupation concurrent with the major population peak at the coast (Jørgensen and Riede, 2019; Hood et al., in press). This corroborates the previous impression that major population packing occurred on the coast and that activity in the interior was minimal at this time (Hood, 2012). Given the significant difference in magnitude between inland and coastal settlements, packing does not seem a sufficient explanation. We suggest actual population growth followed coastal packing, although this is in need of further enquiry.

Highlighting this, the archaeological and rock art records suggest technological and organizational intensification of

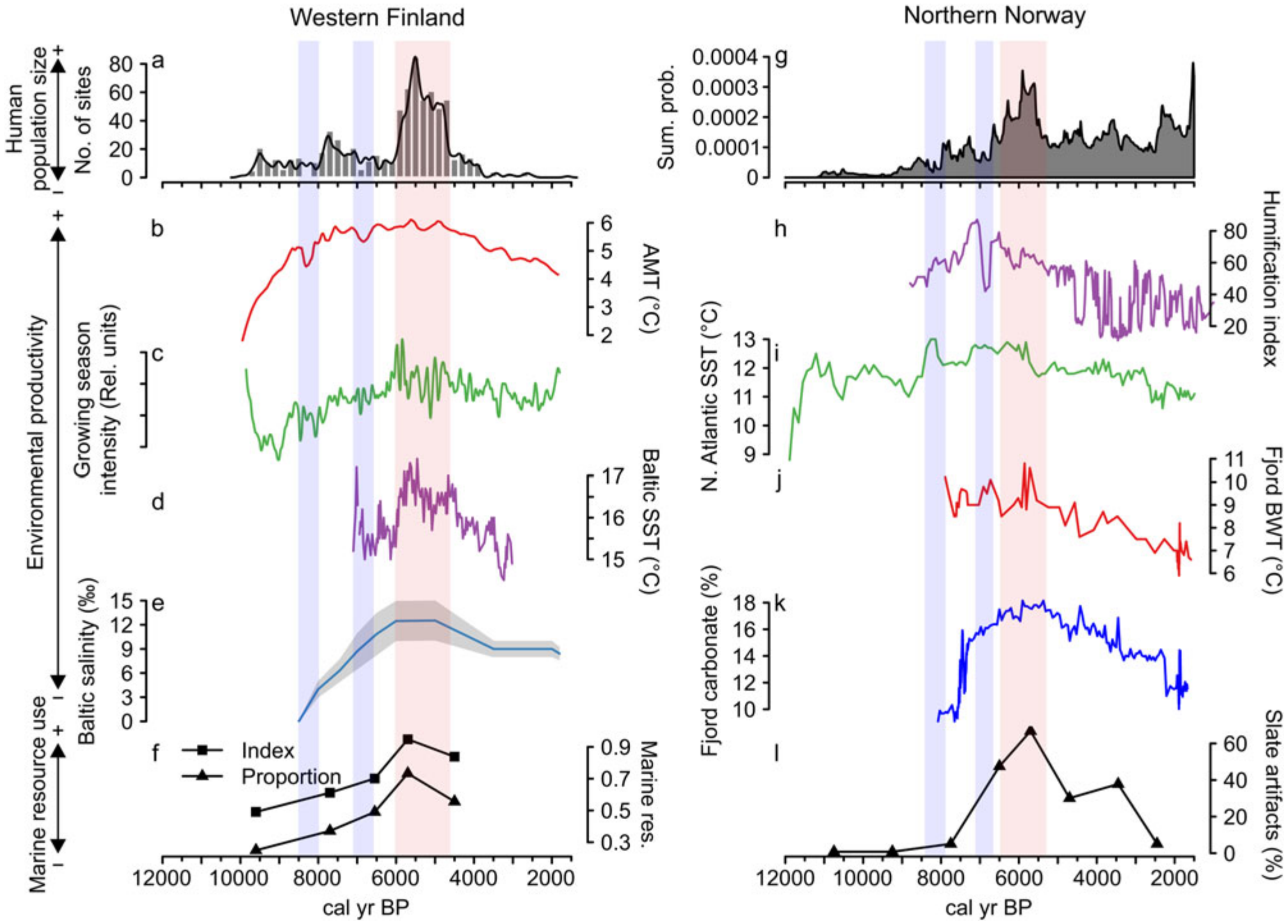

Figure 3. (color online) Combined figure of reconstructed population trends, climate proxy comparisons, and marine resource exploitation indicators: (a) Finnish area population reconstruction; (b) Finnish area annual mean temperature (AMT); (c) Finnish area growing-season intensity; (d) Baltic Sea surface temperature (SST); (e) Baltic Sea salinity; (f) index and proportion of seal bones in Finnish faunal assemblages; (g) Norwegian area population reconstruction; (h) Norwegian evapotranspiration; (i) North Atlantic coastal current temperature (SST); (j) Norwegian fjord bottom water temperature (BWT); (k) Norwegian fjord productivity (carbonate %); and (l) proportion of slate tools in coastal, northern Norwegian lithic assemblages.

marine resources through the introduction of more efficient hunting/processing tools and (most likely) cooperative hunting strategies (Gjerde, 2018). Dietary investigations of the only mid-Holocene human individual currently known from northern Norway (Måløy Island) demonstrate a spectacularly high intake of marine protein (Günther et al., 2018, S1, 12). Discriminating the isotopic signature of marine mammal protein from that of migratory cod is difficult due to comparable trophic levels (Schulting et al., 2016), but migratory cod is by far the most dominant species in the region's faunal record during the time of the population boom (Olsen, 1967; Utne, 1973; Engelstad, 1983; Renouf, 1989). Tentatively, this may indicate adaptive adjustments toward lower-ranked fish resources. Systematic diachronic sampling of biochemical dietary proxies may help resolve these issues in the future.

DISCUSSION

Our main finding is the clear spatial synchronicity in demographic trends and adaptive strategies between two geographically separate human populations. Our results also strongly suggest that this synchronicity is related to the variability in both terrestrial and marine productivity, which themselves are correlated between the two areas. While the details of these human ecodynamics and the pathways toward increased populations and maritime adaptations differ between the two focus regions, the outcomes are comparable. This suggests that the long-term demographic trajectories in both areas were ultimately regulated by climate and its downstream effect on both terrestrial and marine productivity and hence food availability for hunter-gatherers. The high productivity of the mid-Holocene would have increased the environmental carrying capacity, and in concert with highly stable climatic conditions, offered unprecedented potential for human population growth. This seemingly mechanistic climate forcing of human populations is further supported by the synchronous decline in population numbers and environmental productivity after 5500 cal yr BP, as well as by short-term declines at 8200 and 7000 cal yr BP. Thus, our results apparently demonstrate Moran effects in action among human populations. The implication being that climate has the potential to synchronize long-term human population trajectories among foraging economies. Future research would need to investigate to what extent this relation also holds for food-producing populations.

Although our results suggest that climate is the most likely explanation for the spatial synchrony between the northern Norwegian and western Finnish hunter-gatherer populations, other mechanisms may still be in play. The trend correspondence between population size, climate, and adaptive strategies highlights the more generalized problem of what should be ascribed causal primacy among demographic, environmental, and technological factors in bringing about synchronous adaptive strategies: Did marine resource exploitation vary independently of population size, or did the maritime specialization result from changes in population size, thus being density dependent? The latter option fits the concept of marine resources becoming attractive only when population packing restricts terrestrial hunting capabilities, creating an imbalance between human population growth and its (assumed) preference for a terrestrial resource base (Binford, 2001, pp. 188, 210; Kelly, 2013). This is thought to follow from the high handling and initial investment costs in aquatic resource exploitation in order to turn a profit, exemplified by the development of boats, specialized fishing equipment and marine hunting gear, as well as bulk processing and storage (Osborn, 1977; see also Yesner et al., 1980; Steffian et al., 2006; Fitzhugh, 2016). Yet maritime intensification would also require some other factor responsible for the initial population growth necessary to achieve sufficient population packing to mitigate the higher investment costs.

In our case, however, this seems problematic. First, human population growth and marine resource exploitation appear to increase alongside a coupled marine–terrestrial productivity increase. One might point to the significantly fewer trophic levels in high-latitude, terrestrial ecosystems as a possible limitation to terrestrially based human population growth (cf. Steele, 1985; Carr et al., 2003; Steele et al., 2019). The abundance of ungulates is strictly regulated by density-dependent mechanisms in boreal forests (Bergerud et al., 2012, p. 102), and is arguably less resilient in the face of human overexploitation than marine resources (Minc and Smith, 1989; Gunderson, 2000). It is therefore not clear whether continued terrestrial growth results in a linear increase in resource abundance relevant to human economic exploitation. This is an unresolved issue for future research to consider, yet current data do not support scarce terrestrial resources as the driving factor of the regime shift in marine exploitation. Further lacking support is the possibility of a significantly earlier terrestrial productivity peak driving the shift toward intensified marine economies (particularly in light of a wider range of terrestrial proxies from northern Norway [Balascio and Bradley, 2012; Wittmeier et al., 2015; Sjögren and Damm, 2019]). Second, the intensity of marine resource use appears to decline along with declining terrestrial (and marine) productivity. Third, if marine resources are secondary to terrestrial resources, it would make it difficult to explain how aquatic resources could support the population growth observed in our data or how some of the highest population densities in the ethnographic record are found among maritime-adapted hunter-gatherers. For now, we cannot resolve the causal relationship between technological change and population growth. The fact that increase and decrease of marine resource use follow the trends in environmental productivity nevertheless suggests that adaptive changes in our study areas were ultimately subordinate to climate changes.

An alternative to endemic population growth in ecological terms is dispersal between populations, which is another common factor causing spatial synchrony and may pertain to our case as well, for example, through source-sink dynamics (Kawecki, 2004). Agriculture was broadly adopted across northern parts of continental Europe, southern Scandinavia, and the British Isles ca. 6000 cal yr BP. This created an unparalleled population boom roughly synchronous to the pattern observed in the population proxies from western Finland and northern Norway. Intuitively, this might suggest that the mid-Holocene population peak in our study area relates to agricultural expansion, either directly through incoming farmers contributing to the population growth or indirectly by displacing hunter-gatherers into northern "foraging refugia," as suggested for central Europe (Silva and Vander Linden, 2017). The direct influence of farmers is problematic, however, as solid evidence for agriculture in our study areas is significantly younger than the 6000 cal yr BP population event (Sjögren, 2009, p. 707; Sjögren and Arntzen, 2013; Lahtinen et al., 2017; cf. Mökkönen, 2009). Indirect influences of agriculture are equally problematic. First, the hunter-gatherer population in northern Norway was already growing some 500 yr before agriculture was introduced to southern Scandinavia. The same pattern of pre-agricultural population growth is evident when reviewing the population reconstruction of Holocene Finland in its entirety (Tallavaara et al., 2010; Tallavaara and Seppä, 2012). Second, displacement of hunter-gatherers from south to north would neither explain the remarkable population decline after 6000 cal yr BP or short-term declines at 8200 and 7000 cal yr BP.

In the case of observed synchronicity among human populations, an additional synchronizing factor of social interactions through trade and networks has been proposed (Freeman et al., 2018). The dissemination of improved subsistence technologies could tentatively drive synchronous demographic and adaptive strategies within our study areas. If so, cultural diffusion might facilitate the observed shift in marine exploitation regime while also contributing to population growth. This is particularly pertinent for two technological industries in the area: slate tools and early pottery.

The slate index (Fig. 3i) demonstrates strong correspondence with population dynamics in Norway. Assuming that slate tools are superior in marine resource processing, one might expect slate industries to be of comparable importance among the coastal population of the Finnish area. No such quantitative data set or overview for Finland currently exists. However, there are some similarities in slate technology that may suggest social networking in action between Finland and Norway (cf. Äyräpää, 1950; Huurre, 1983). Such is demonstrated by the long (100–150 mm) and slender (10–15 mm) Pyheensilta/Nyelv lance points occurring in both areas. A review of a large set of lance points, including a depot containing points at various stages of completion (Hesjedal et al., 1996, p. 70), demonstrates remarkable standardization in production technique and morphometric qualities. The standardized breadth and hafting characteristics of Pyheensilta points, as well as the frequent resharpening of broken distal ends, reflect optimal characteristics for effective marine hunting. Maritime technologies are strongly associated with multicomponent and replaceable components, given the complexity of hunting on water and the need for quick replacement/repair of hunting gear—a "maintainable" characteristic within an otherwise mostly "reliable" technology (sensu Bleed, 1986). We therefore suggest that the Pyheensilta/Nyelv lances provide a telling example of shared marine subsistence technology. We equally maintain that the adoption of common technologies followed similar adaptive strategies to shared environmental conditions.

The other significant change with potential ramifications for the synchronous mid-Holocene population and marine boom-and-bust cycles is the introduction of ceramic technology. Ceramics dispersed throughout northern and eastern Fennoscandia around 7200 cal yr BP in the form of Early Comb Ware—concurrent with the uptake of slate technology in northern Norway. The demographic impact of ceramic technologies is, tentatively, the enhancement of the nutritional uptake of various foodstuffs through cooking, which may reduce child mortality (Jordan and Zvelebil, 2010, p. 54). Interestingly, the beginning of pottery production in our study areas roughly coincides with the beginning of the mid-Holocene population growth and increase in marine resource use proxies, when Finnish sites (<6000 cal yr BP) are characterized by large quantities of pottery (Nuñez, 1990; Pesonen and Leskinen, 2009). Although it has been suggested that the uptake of pottery was related to the intensification of marine resources, lipid analyses of food crusts on pottery walls suggest a wide range of resources were processed in the vessels (Cramp et al., 2014; Pääkkönen et al., 2016; Papakosta and Pesonen, 2019).

Crucially, major discrepancies in the uptake and maintenance of ceramic technologies in the area go against subsistence technologies as a causal factor in the observed synchrony. In Finland, pottery was in use throughout prehistory, despite the reduced importance of marine resources and the population decline after 5000 cal yr BP. In northern Norway, however, pottery did not disperse beyond the very easternmost region and was likely a short-lived effervescence based on the short duration and small number of ceramics recovered, with a complete lack of later Comb Ceramic phases (cf. Skandfer, 2003; Hood and Helama, 2010). There are potential functional reasons for this discrepancy, beyond the greater geographical proximity of the Finnish area to dispersive centers of ceramic technology in Eurasia. The eco-setting of western Finland, which was likely more conducive to year-round habitation, in combination with the evidently strong emphasis on estuarine/riverine fisheries, meant that populations could benefit from ceramics for bulk processing and storage. In Norway, there is to date no evidence to support surplus production of riverine/estuarine resources throughout the Stone Age (see Engelstad, 1984; Renouf, 1986, p. 10). However, mass processing and storage through passive technologies such as preservation through air-drying of stockfish has deep roots in Norway (Perdikaris, 1999; Star et al., 2017). The climatic conditions required for such preservative techniques are very specific to the northern Norwegian coast and are not met in the Finnish area. Although archaeologically elusive, we see no reason why the basic innovation of leaving fish to dry by itself would not have been practiced already during the mid-Holocene. If so, the appeal of pottery may have been negligible to the Norwegian population.

We cannot exclude the effects of migration, social interactions, or cultural diffusion. It is conceivable that the adoption of new and potentially improved subsistence technologies occurring simultaneously across northern Europe contributed to the growth phase of the 6500/6000 cal yr BP population cycle. The explanatory power of subsistence technology, however, is undermined by the fact that the population decline occurred independently of changes in subsistence technologies in our study areas and by the fact that both population growth and decline phases coincided with environmental changes. We therefore believe that the observed synchronicity in the long-term population dynamics is better explained by climate-induced variability in environmental productivity acting over large areas, albeit at much larger temporal scales than typically observed in ecological research. This result is at odds with the conclusion of Freeman et al. (2018), who found that environmental variability made no discernible impact on population synchrony. Instead, they suggested that societies dependent on organic sources of energy appear no more synchronous with solar energy fluctuations than fossil fuel–based economies. However, their conclusions are hampered by the use of sunspot data as a measure of environmental variability. Although solar energy is the primary driver of Earth's climate, the influence of solar activity cycles on climatic variability appears to be limited at best (George and Telford, 2017; Schurer et al., 2014; Telford et al., 2015; Turner et al., 2016).

Instead, net primary productivity (NPP) is the crucial driver of energy availability for the immediate-return, organic economies most typical of hunter-gatherers (Tallavaara et al., 2018), as opposed to economies reliant on stored energy reserves (Kander et al., 2013). NPP is controlled by temperature and precipitation, which can be correlated across distances of up to 5000 km, but not globally (Koenig, 2002). Therefore, there is no justification for using any single record of climate or energy availability, such as Greenland ice cores or sunspot data, when analyzing synchrony among prehistoric populations. In addition, taphonomic loss of archaeological material must be taken into account, as the exponential-like shape prevalent across the mean trends of human proxy records may well be influenced by taphonomic processes (Surovell and Brantingham, 2007; Surovell et al., 2009).

Consequently, Freeman et al. (2018) do not properly address environmental variability or energy availability as a potential driver of synchrony. However, they demonstrate that spatial synchrony decreases with distance between proxy records. Importantly, the adjacent U.S. states Arizona and New Mexico could make for a convincing case in which synchrony is best explained by social interaction and cultural diffusion. However, geographical affinity also implies being subjected to similar environmental parameters. Without further investigation of archaeological and environmental records at the regional scale, spatial proximity is not in itself a sufficient condition to come to a conclusion about the causes of synchronicity. We therefore reiterate Koenig's (2002, p. 288) argument, stating that "patterns of spatial autocorrelation in environmental factors should be carefully considered before concluding that synchrony in any particular system is driven by some factor beyond environmental correlation."

Despite some indications that both foraging and early farming communities were equally susceptible to climate change (Bevan et al., 2017; Warden et al., 2017), hunter-gatherer populations are generally assumed to be more directly controlled by NPP (Tallavaara et al., 2018). Still, hunter-gatherers relying on marine resources may take a hybrid form through delayed-return systems, as bulk processing and storage of energy for lean-season consumption is a common characteristic of many northern, maritime groups (Fitzhugh, 2016). Such delayed-return economies help overcome the limitations imposed by the direct consumption characterizing organic economies. Either way, the archaeological record suggests that the maritime adaptations under study could only mitigate low-amplitude annual variations and at best delay specific returns on an interannual scale. This is not sufficient to significantly boost carrying capacities or mitigate increased variation in resource abundance like modern economies, which are basically extreme delayed-return systems relying on nuclear or fossil fuels (and therefore unsuitable as a comparative case). The limited and short-term mitigation capabilities of pre-industrial economic systems in significantly delaying returns would explain the inability of the populations to avoid decline along with reduced environmental productivity before 5000 cal yr BP.

It seems that convergent cultural evolution toward more energy-consuming economies becomes important *after* the adoption of intensified agriculture relying on active niche construction and yielding reliable surpluses. Consequently, we suggest that intensified economies and social interaction networks have limited impact on long-term hunter-gatherer population trajectories beyond what is already proscribed by external, environmental drivers.

CONCLUSION

This paper reviewed environmental productivity in relation to subsistence strategies in aquatic settings to unpack the drivers of synchrony between separate human populations. We presented a case study of two northern European subregions and demonstrated significantly synchronous trends across demographic, adaptive, and environmental parameters. Based on an evaluation of different hypotheses, we suggested that the synchronous human ecodynamic trends across Holocene coastal Fennoscandia were a result of shared variability in environmental productivity. Considering that the population trajectories of the two separate areas display remarkable synchronicity and that these follow attendant climate variability in a lockstep manner, the results lend support to the notion that changes in environmental productivity more or less directly induce changes in hunter-gatherer population size. The peak in productivity during the mid-Holocene would have drastically increased the environmental carrying capacity and so provided unprecedented human demographic growth potential. In addition, the long-term stability of the environment during the mid-Holocene may also have been a contributory factor to the observed human ecodynamics, dampening the amplitude of fluctuations that might otherwise be difficult to mitigate with short-duration, delayed-return, risk-reduction measures (Riede et al., 2018).

Our results further demonstrate that major economic changes correspond to demographic and environmental dynamics as evidenced by a suite of marine resource exploitation proxies. It is striking that both populations developed similar adaptive strategies, relying heavily on marine resources. Unpacking the causal mechanisms behind this regime shift toward intensive marine exploitation is beyond our ability at this point. The possibility that population growth was driven primarily by a change in subsistence technology, however, is undermined by the fact that the population decline apparently occurred independent of changes in subsistence technologies in our study areas and by the fact that both population growth and decline phases coincide with environmental changes. More detailed technological investigations are needed in order to properly understand these relations.

Future research should aim at establishing the extent to which the mid-Holocene productivity increase was coupled between marine and terrestrial environments and determining the human implications of a potential imbalance in marine versus terrestrial ecosystem responses to large-scale climate change. If the productivity increase was actually stronger in the marine environment, it may provide a working hypothesis as to why we observe economic, technological, and social-organizational shifts in mid-Holocene northeastern Fennoscandia. However, the paleoproductivity proxies presented here suggest a coupled response between marine and terrestrial ecosystems.

Another venue for further exploration is potential threshold effects operational in maritime adaptations. It is conceivable that the profitability of marine resource exploitation increases nonlinearly, given all its costs (high handling and initial investments), whenever marine productivity increases above some critical level. The pathways responsible for steering ocean–atmospheric interactions are multifaceted

(Wunsch, 2005; Yu and Weller, 2007) and may imply more complex climatic drivers of marine productivity compared with terrestrial productivity (Bromley et al., 1967; Behrenfeld et al., 2006; Meehl et al., 2011; Holt et al., 2016; Schmitt, 2018). It is necessary to identify and model various ecosystem components and thermal thresholds to evaluate this properly. Yet thresholds imply sharp changes in resource use between different system states, while our data indicate rather gradual changes in marine resource use in both areas. Identifying and distinguishing between thresholds versus gradual changes is fundamentally problematic in past ecodynamic systems due to issues of sampling and resolution. Yet the fact that the intensification and deintensification of maritime economies occurred over a multimillennial period clearly indicate gradual developmental trends.

Although a previous study found only minimal evidence for environmental variability as a cause of synchronicity (Freeman et al., 2018), the Fennoscandian archaeological record clearly demonstrates the important role of spatially correlated environmental influences—Moran effects—in creating spatial synchrony among hunter-gatherer populations. The implication is, contrary to Freeman et al. (2018), that intensified economies and social interaction networks have limited impact on long-term hunter-gatherer population trajectories beyond what is already proscribed by external, environmental drivers.

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Paper 4

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Scalar Effects in Ground Slate Technology and the Adaptive Consequences for Circumpolar Maritime Hunter-Gatherers

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Abstract
Ground slate technology is a trademark of circumpolar hunter-gatherers occupying coastal ecotones. However, a causal framework for explaining what drives the apparent adaptive success of slate technology is lacking. Attempting to remedy this, the current paper provides the first palaeodemographic and environmentally informed review of a maritime slate complex. Employing what is arguably the best documented and contextually controlled slate industry in Holocene Eurasia as a high-resolution case study (the Arctic Norwegian slate industry), the system components of demography, ecology and technology are integrated to get at (1) why slate technology appears to be a particular maritime success, (2) what causal contribution slate technology makes to population-scale adaptive success, (3) why slate technology was eventually abandoned. Based on extensive empirical investigations, the results demonstrate synchronous changes in population size, maritime intensification and the use of slate technologies. It is suggested that the mechanism responsible for this correspondence is that the slate industry facilitated a heightened adaptive success, reinforcing population growth and maritime intensification. Technological results indicate that superior properties for standardization make the slate technology ideal for establishing a scale economy in maritime resource exploitation when surpassing critical thresholds in population packing. Causal modelling demonstrates that, under particular demographic and ecological conditions, the scalar properties of slate technologies can offset high- and density-dependent start-up costs, by increasing return rates and reducing handling costs of hunting/processing of marine resources. Satisfying all criteria for tool "efficiency", it is concluded that slate industries have causal efficacy as an "enabling technology" in circumpolar, maritime settings.

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Keywords Economies of scale · Ground slate technology · Maritime adaptation · Circumpolar archaeology · Arctic Norway · Maritime intensification

Introduction

This paper deals with two general issues in human behavioural ecology and evolutionary archaeology:

1. The role of adaptive strategies, mediated through technology, in shaping long-term population trajectories.
2. The development of middle-range mechanisms better-explaining feedback loops between demographic parameters and technological capabilities of a population.

A striking case conceptualizing these relations is the maritime ground slate technologies. Slate technology is a trademark of circumpolar hunter-gatherers occupying coastal ecotones. Maritime slate traditions developed independently at multiple innovation centres in the circumpolar Holocene and were part of convergent evolution between geographically distinct populations that occupy coastal niches (Fig. 1) (B. Fitzhugh 2016; W. Fitzhugh 1975, 2002). In fact, the degree to which these technological traditions converge is astonishing. Slate technologies thus make the ideal case for comparative, human ecological research targeting the issues stated above. Unfortunately, the drivers of initial uptake, long-term maintenance and the adaptive implications of slate industries are not well understood. What is lacking is a causal framework able to explain these phenomena, as well as high-resolution case studies that integrate the system components of demography, ecology and technology. This paper aims at remedying this and contributes to our understanding of technological evolution and adaptability among prehistoric hunter-gatherers.

It is important to reexamine the human ecodynamics of coastal hunter-gatherers in relation to maritime subsistence technologies, as it may shed new light on fundamental evolutionary issues concerning the origins and causes of human adaptive diversification, *e.g.* marine resource exploitation. Maritime adaptations have been considered an Upper Palaeolithic/Mesolithic newcomer among human adaptive strategies and a consequence of the economic diversification made possible by stabilizing Holocene environments (Stiner, 2001; *cf.* Piperno, 2011; Piperno and Pearsall, 1998). However, accumulating evidence pushes back the history of aquatic resource exploitation (Erlandson 2001, pp. 306–308; *cf.* Langejans *et al.* 2012). Rather, aquatic environments have been an integral part of the evolution of anatomically modern humans (Geoff Bailey 2015). Regardless of its evolutionary time depth, the so-called aquatic turn of increased aquatic resource exploitation during the Holocene has been considered one of the major research questions in archaeology (Binford 1990). The evolution of maritime slate technologies may be a crucial stepping stone for this very purpose.

Here I attempt to provide a two-level account of a maritime slate industry in terms of both its *general* adaptive advantages (functional level) and the *particular* historical/diachronic process by which its attendant behavioural suit developed (historical level) (Codding and Jones 2010). I examine the Arctic Norwegian slate industry as a case study. Although the evolutionary histories of the various slate industries are regionally specific, this paper provides important comparative insight in testing predictions of global interest.

Firstly, the function of slate technology is discussed. Secondly, the proposed drivers of slate technology uptake are reviewed. Thirdly, an extensive effort is made to flesh out the case study by presenting the evidence for maritime intensification in Arctic Norway during the mid-Holocene, as such, a review has not been made before. It is necessary to establish changes in maritime adaptation and economic intensification given the critical links between them and the subsistence technologies explored here. Such a review is also made relevant by recent studies establishing the palaeodemographic and environmental dynamics in the area (E. K. Jørgensen 2018; E. K. Jørgensen *et al.* 2020; E. K. Jørgensen and Riede 2019), making it possible to investigate technological changes in tandem with these.

The Arctic Norwegian slate industry is subjected to a set of analyses, and the results of the technological analysis are presented. Based on the total review of the Arctic Norwegian case study, the paper develops a causal model of the mechanisms that determine the adaptive contribution of slate technologies to maritime-adapted populations, and how they relate to specific ecological, demographic and temporal variables.

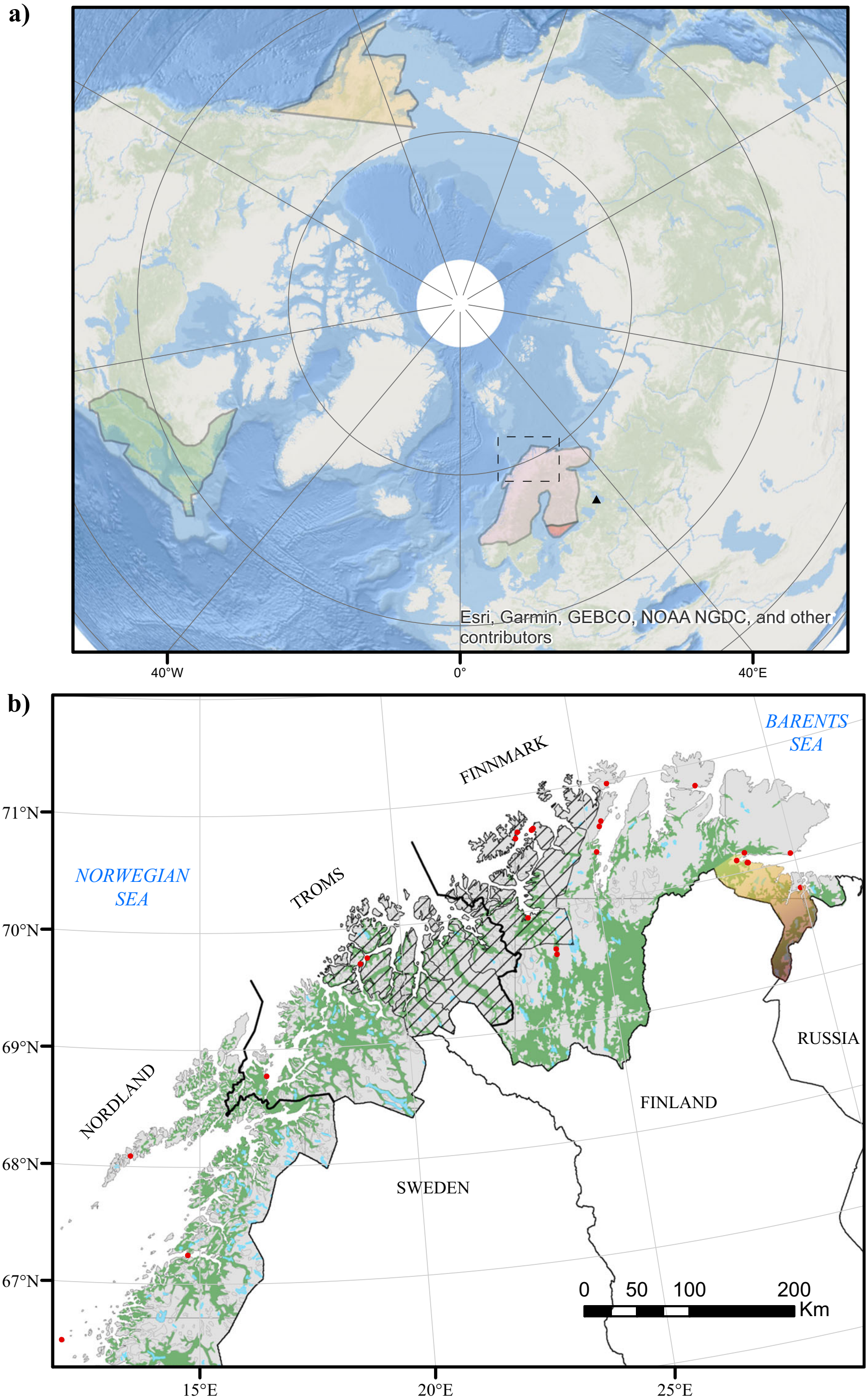
Background

It was early on pointed out that slate technology seems to be a trademark of maritime hunter-gatherers in the circumpolar north (Brøgger 1909; Clark 1980; W. Fitzhugh 1975; Gjessing 1944; Ritchie 1969). However, reviewing the global literature on slate technology reveals a striking pattern of peaking interest during the late 1970s and near-total neglect ever since. Most studies of maritime slate technology are of North American origin, with a particular focus on the Pacific Northwest coast (Oregon to Alaska), although some studies from Russian Bering and Kamchatka, as well as the Eastern American Arctic (Maine/Labrador coast and Greenland), do exist.

In the Eurasian Arctic, however, the picture is very different. Despite its diagnostic and culture-historical significance, Fennoscandian and Russian slate technology is generally poorly understood. This is in large part due to the low degree of archaeological activity in the Eurasian Arctic, combined with a scholarly preoccupation with flint and flint-like raw materials more comparable with the archaeological record of continental Europe.

The only functional description and regional contextualization of Eurasian slate complexes were made in 1974 by William Fitzhugh. He attempted to synthesize the spatiotemporal distribution and functional variation between separate slate complexes of the Scandinavian Late Stone Age (W. Fitzhugh 1974). Despite the outdated spatiotemporal distribution therein (due to the very limited slate inventories and few absolute dates at the time), his "functional hypothesis for the development of Scandinavian slate technology" is just as pertinent today and, indeed, has become more or less uncontested.

Previously, the multiple Fennoscandic slate complexes were described within a diffusionist paradigm as a maritime innovation native to the northern regions and thought to have dispersed southwards (Gjessing 1944, 1953). This was later reiterated by the lack of slate knives south of 62° latitude in Norway, taken to reflect different


a)
Esri, Garmin, GEBCO, NOAA NGDC, and other contributors
40°W
0°
40°E
b)
BARENTS SEA
FINNMARK
NORWEGIAN SEA
TROMS
NORDLAND
RUSSIA
FINLAND
SWEDEN
71°N
70°N
69°N
68°N
67°N
0
50
100
200
Km
15°E
20°E
25°E

◀ **Fig 1** Area map providing **a** overview of the circumpolar region with the general location of the three most important maritime slate complexes. Pink: Fennoscandian slate distribution. Green: Maritime Archaic. Orange: Pacific Northwest (PNW) coast. Red: Suomusjärvi complex. Triangle marker: Onega/Karelian metatuffite (greenstone/green slate) source. It is likely that Fennoscandia and NW Russia contain multiple slate complexes and that these had variable spatiotemporal distributions. However, such detailed knowledge does not currently exist. The main distribution area of slate technologies in Fennoscandia is therefore mapped in unison. Basemap data by Esri, GEBCO, NOAA, National Geographic, DeLorme, HERE, Geonames.org, and other contributors. **b** Map of the Arctic Norwegian case study area, displaying sites mentioned in the text and important assemblages that constitute part of the dataset (see Supplementary Information). The hatched area corresponds to the catchment area for the palaeodemographic model. Radial brown area marks the limited distribution of Early Comb Ware ceramics in Norway with increasing density toward interior Finland and Russia. Ceramic distribution data adapted from (Skandfer 2003, p. 377). Regional map data provided by Kartverket

economic adaptations along the coast, in that marine mammals were exploited much more intensively in the north than in the south (Søborg 1988; *cf.* Nygaard 1989, p. 91). This supposedly followed from the fact that slate projectile points have a much wider distribution than slate knives, whose southern distribution is clearly demarcated by Statt (Møre and Romsdal County).[1] This understanding has been corroborated by more recent data accumulation (*cf.* Bjerck 2008) and mirrors the demarcated distribution of other object categories (Bergsvik 2004).

Beyond Norway, only some attention has been directed at slate technology in Sweden, Finland and NW Russia (Äyräpää 1950; Baudou 1992, p. 80; Huurre 1983; Nuñez 1998; Olofsson 2015, p. 4; Tarasov 2011). Possibly most renowned is the Mesolithic Suomusjärvi complex (see Fig. 1) of SW Finland which contains the hitherto oldest known ground slate technology globally, with leaf-shaped slate points dating back as far as 10.000 cal BP (Luho 1967; Nuñez 1998, p. 109; Matiskainen 1989; *cf.* Olofsson 2003, p. 8). While the slate industry of Arctic Norway has sporadically been addressed in research, the most recent treatment emphasized non-physical properties (Sommerseth 1997). The result is that to date, no technological studies of Eurasian slate technology exist. It is therefore necessary to synthesize existing data and update the low-resolution conception of northern Eurasian slate complexes and their situation within a wider biocultural and adaptive framework. Based on the wealth of material excavated since Fitzhugh's paper and the rapid accumulation of more tightly controlled and dated slate assemblages, it is now possible to make an updated review of the role of slate technology in selected areas. As a total review of Eurasian slate technology is currently inconceivable, I here attempt such a review of the more limited case of the Arctic Norwegian slate industry.

This is justified as the archaeological record of the Norwegian coast currently holds the richest and best-documented slate industry across the Eurasian Arctic. The advent of the ground slate technology marks the transition from the Early Stone Age (Late Mesolithic) to the Late Stone Age (Early Neolithic) at 7000 cal BP in Arctic Norway. It developed into a significant technological tradition throughout the next 5000 years. This slate industry mainly consists of two functional tool categories, *i.e.* knives and projectiles. Multiple classificatory types have been distinguished, primarily by Gjessing (1942), as represented in (Fig. 2). No quantitative or systematic review has been conducted on the informal slate typologies, yet ongoing investigations using

[1] Although strong, this demarcation is not waterproof. Some double-edged slate knives and a number of ornamented slate pendants are known from Rogaland County, south of the demarcation line (Gjessing 1920, pp. 269, 271, 301).

Fig 2 Collage illustrating a selection of important slate tool types. Upper line projectiles, lower line knives. Objects are arranged in relative chronological order, from older (left) to younger (right). Note the variation in raw material and hafting/handle design. **a** Slettnes, bifacial, double pointed. **b** Nyelv, slender tanged lance. **c** Leaf-shaped point, with notches. **d** Sama, tanged with straight or hanging barbs. **e** Sunderøy, fluted. **f** Animal-headed dagger. **g** Double-edged knife, ornamented. **h** Boot-shaped knife. **i** Miniature knife, of the most common single-edge knife type. **j** Ulu, with handle. Credits: The Arctic University Museum, Tromsø/Norway. Photos by Mari Karlstad. Collage and editing by the author

morphometric and multiple correspondence analysis seem to conform more or less to the intuitive types.

The distribution of geological slate formations is paramount to understanding the technological organization and evolution of slate technologies. Geologically, slate is a foliated metamorphic rock that can cleave perpendicular to the original bedding planes, and the term can include a range of metamorphic products that share a family resemblance, such as slate "proper", schists and meta-arkose. The material preferred by prehistoric lithic tool producers has been called "slate" by archaeologists, but geologically, it is actually sedimentary shale/mudstone. Geological metamorphic slates are known from many areas across Fennoscandia, but tool-grade sedimentary "slate" is not uniformly distributed. Such are rather closely associated with the sedimentary rocks were deposited around the edges of the Baltic Shield that later was exposed through the formation of the Caledonian mountain range of the Scandinavian interior (for interactive geological maps of the area, see http://www.europe-geology.eu/onshore-geology/geological-map/onegeologyeurope/). A number of formations within these sedimentary units contain rocks that archaeologists would call "slate" and which resemble materials known from archaeological sites, but most formations contain rocks too hard or too metamorphosed to be suitable as tool stone. Thus, the actual distribution of raw material sources suitable for slate tool production is more restricted than can be discerned from geological maps. Unfortunately, the distribution of "archaeological slate" is poorly studied across Fennoscandia. However, there was clearly a willingness to invest in costly extractive and distributive efforts deep into the interior, given the restricted availability of banded slate sources in the central Caledonian mountains and the broad distribution of banded slate tools at coastal sites (Hallgren in press, 2012, pp. 150–1511). This, combined with the fact that the only major sedimentary "slate"-bearing geological formations present anywhere on the Fennoscandic coast are located in Finnmark County, Arctic Norway, where they outcrop extensively, makes this particular region an ideal case study for the development of maritime slate technology.

There is an important distinction to be made with the geology of Finland and NW Russia, primarily consisting of volcanic and metamorphic basement rocks of the Baltic Shield, with locally preserved volcano-sedimentary greenstone belts. The greenstone belts contain metasedimentary rocks of varying metamorphic grades, some of which are reminiscent of archaeological "slate", such as schists and phyllites (Nuñez 1998, p. 109). The archaeological literature refers to a material termed "Onega green slate", which has a known source on the western bank of Lake Onega (see Fig. 1). It has primarily been used for making a rather distinct toolkit consisting of axes, adzes, picks and gouges (including the Suomusjärvi), quite different from the slate technologies known on the Norwegian coast. However, this material is not sedimentary "slate" but a metatuffite—a metamorphosed volcanic tuff (Nordqvist 2018, p. 72; Tarasov and Stafeev 2014, p. 244). It is only haphazardly laminated and does not display proper bedding planes as slate does (Nuñez 1998, p. 108).

Function of Slate Tools: Adaptive Benefits for Maritime Adaptation

Initially, it is necessary to establish the marine connection of the slate industry and its function within a maritime economy. Slate tools are often claimed to have been used for marine mammal hunting and processing. Based on the striking distribution of slate complexes among maritime HG's in the circumpolar area (*e.g.* Fennoscandia, Kamchatka, eastern Aleuts, Alaska, Labrador, Greenland), the consistency with which this occurs, the rarity among terrestrial populations and the striking cross-cultural similarities in tool types, makes the maritime link seems rather convincing. Apparently, there are some functional properties of slate tools that make them preferable over other technologies to maritime foragers.

Some exceptions do exist, most notably in the terrestrial setting of the Karelian/Onega and Laurentian Archaic complexes, that both made use of slate technology. However, the slate proportion seems to have been minor in both cases. In addition, some notable maritime groups did not rely on slate technologies, such as the Siberian north coast and early Palaeoeskimo groups. However, a common characteristic of these groups is hyper-mobility. Slate was later adopted by multiple groups in the North American Arctic, such as Dorset, Thule, Norton and Kachemak. Too few sites are now from the Siberian north coast to conclude on the importance of slate technologies and provide an interesting venue for future research, together with sub-Antarctic areas (*cf.* Sutton *et al.* 1982).

The correlation between maritime adaptations and the use of slate tools does not present us with an answer to the question "why". However, several advantageous properties have previously been proposed:

- The plasticity of slate materials allows working into a range of shapes and sizes difficult to match by other lithic materials[2] (Nuñez 1998).
- Provide durable and blunt edges for working soft tissues (W. Fitzhugh 1974, p. 53).
- Slate is less clogged by fat when working tissues or processing skins, compared with the porous structure of wood and bone (W. Fitzhugh 1974, p. 53; *cf.* Frink *et al.* 2003, p. 119).
- Slate can be easily re-sharpened, at minimal risk of tool damage (Hayden 1987, p. 41). Re-sharpening of slate tools has minimal impact and can be performed repeatedly without a significant mass loss (W. Fitzhugh 1974, p. 53).
- Slate can be worked into long and regular edges that are useful for skin preparation (W. Fitzhugh 1974, p. 53). Similar bone tools can be made, but bone elements do not have the morphology needed for larger, curved knives. Regardless, the use of slate reduces the need for larger bone pieces (that may be in short demand for other purposes).
- Well suited for poison hunting, as demonstrated in the aconite-poisoned dart whaling practice in the Aleutian Islands (Crowell 1994; Heizer 1943; Osborn 2004), although, to my knowledge, no studies have demonstrated the prehistoric occurrence of poison-coated slate tools.

More recent experimental studies are inconclusive regarding the universal advantage of slate technologies and instead stress context-specific benefits. The very limited body of experimental studies on slate tool production and use suggest that slate industries are most cost-effective in economies based on medium- to large-scale storage of processed products (Graesch 2007). Others have proposed that the benefit of slate tools becomes apparent only in cases lacking equally efficient processing technologies (Morin 2004, p. 311). The former recognizes the high start-up costs in slate tool production, but also that there are particular advantages to this industry under conditions of mass processing. This fact corresponds well with the common feature of seasonal migratory behaviour among many of the economically most significant species in the circumpolar area, both in terrestrial and marine environments. However, there are experimental indices that slate technologies are functionally superior to other lithic technologies for the particular purpose of skin processing as the blunt edges reduce the risk of perforating the skin (Frink *et al.* 2003, p. 119; Wilhelmsson 1996).

From an analytic point of view, there are alternative ways of conceptualizing technologies when facing insufficient empirical data for hypothesis testing. A useful approach is the parameters of efficiency and optimization in lithic technologies, established in the classic work by (Bleed 1986, p. 739, 1991) and further developed by (Bousman 1993, p. 69). The argument states that hunter-gatherer subsistence

[2] A particularly interesting example of slate use outside the context of circumpolar maritime adaptations is found in parts of Korea (potentially also China and Japan), where slate tools were adopted by peripheral populations during metallurgic periods in order to mimic bronze casting (Ritsumeikan 2007)—further corroborating the plasticity of slate (Nuñez 1998).

technologies mainly conform to one of two quality sets in lithic technologies, prioritizing either:

1) Maintainable designs that are simple, portable and expedient, made for general purposes that arise opportunistically or
2) Reliable designs that are complex, highly specialized and robust to ensure stable operations during critical and limited periods.

The technological preference of a specific group is a function of resource availability, adaptive strategies and mobility patterns. Mind you, these system designs are not dichotomous. Rather, they should be viewed as different vectors in a multidimensional space of technological efficiency. These have been applied to slate technology in Table 1.

In determining the adaptive gain of slate technology, I suggest an additional factor should be added to the above analytic scheme. The primary advantage of slate, I claim, is the material's potential for *standardization*. No other lithic materials allow the same degree of standardized production of exact copies as slate does. This is evidenced by the remarkably uniform debitage left behind by the "chocolate bar" production technique, in which evenly spaced furrows are sawed into standardized slate blanks before snapped into pieces—also known as "pips" (originally discussed in (Clark 1982; Hinsch 1957; Tarasov 2011)).[3] The result is a production concept that generates highly standardized products independent of individual raw material tablets and amendable to a multitude of tool types (see Fig. 7 in the "Results" section). In addition, slate as a raw material is highly formable, accepting being worked into almost any form (sensu Nuñez 1998). Although microblade production in prime quality, cryptocrystalline materials may achieve high degrees of standardization (Fisher 2006), it remains partly limited to within-core/nodule standardization. Furthermore, the production technique is not amendable to standardization beyond the "single purpose" of making blade-based products. The high controllability of slate as a raw material, combined with its low susceptibility to critical production errors, might suggest that it is easier to gain high levels of effective/successful products from sawing and grinding of slate than from chipped tool production.

The high potential for standardization in slate tool production is significant because it allows the optimization of all the efficiency parameters noted in Table 1:

- Standardized products are more reliable as they reduce the variation in performance characteristics of individual products.
- Standardization increases utility per unit of raw material, making better use of potentially scarce or costly resources.
- Standardized designs are easily maintainable as redundant replaceable parts can be on hold.
- Standardization also contributes to the efficiency of the production sequence, *e.g.* through serial- and/or mass production.
- Additionally, standardized production sequences are more suitable for the division of labour and task distribution. The opposite case, in which a single expert must perform all tasks of the production sequence, is significantly less efficient.

[3] A demonstration of the production technique is available at https://www.youtube.com/watch?v=eJyxXpTylfw.

Table 1 Parameters for evaluating technological efficiency from (Bleed 1986, p. 739; Bousman 1993, p. 69), applied to the slate industry

Quality	Efficiency type	Example
Expedient	Reduced production time	Increased utility per time unit
Maintainable	Increased use life	Increased tool longevity/reduced replacement rate
Reliable	Increased effectiveness	Increased return rates
Efficient	Increased production volume	Increased utility per unit of raw material

Slate technologies seem to make for a rare case of optimizing the advantageous properties of both maintainable and reliable technologies. Reviewing components of maritime slate technology in this context suggests that it satisfies more or less all criteria of "efficient technologies", potentially making it into a "super-efficient" technology—in the sense of transcending and combining the individual efficiency parameters.

Causes of Slate Uptake

Granting the functional properties of slate technologies in maritime economies, it does not in itself provide sufficient explanation for the drivers of *initial innovation/uptake* on multiple occasions and convergent technological evolution throughout the Holocene circumpolar region. Doing so requires establishing what "problem" specific components of slate technologies are thought to solve and their advantages over other alternatives. Multiple scenarios have been proposed:

The "Lacking Alternatives" Hypothesis

On both sides of the Atlantic, the general lack of high-quality cryptocrystalline raw material in the circumpolar region has been proposed as a potential driver of the uptake of slate.

In Europe, it was argued that the initial uptake of the hitherto oldest known slate use (Suomusjärvi complex), followed the westward colonization into Finland from the East European Plain, by which the lack of flint and flint-like materials west of Onega resulted in experimentation with local raw materials and the innovation of slate technology as a substitute (Nuñez 1998). A similar argument was later proposed for southeast Alaska, claiming that local abundance of slate beach cobblestones combined with the lack of high-quality cryptocrystalline lithic materials eventually drove the development of local slate use over imported obsidian (B. Fitzhugh 2004, p. 34)—a process thought to coincide with landscape infilling and establishment of territories (Moss 2004, p. 186).

The Arctic Norwegian case contradicts the "lacking alternatives hypothesis". The coast had been successfully inhabited for nearly 5000 years prior to the adoption of slate, exploiting marine resources using a variety of local lithic materials and bone tools.

A wood scarcity hypothesis has also been proposed, claiming the slate innovation was a response to the colonization of wood-depleted areas (Osborn 2004, p. 147). The lack of organic materials (wood) for a number of functional tasks would increase the pressure to find effective alternatives that reduce the need for scarce wood resources. This is thought to have contributed to more complex, multi-component tools. However, it is not clear if slate technology is a direct response or an indirect by-product of the need to experiment with alternative raw materials. Either way, this scenario is thoroughly contradicted by the Fennoscandian slate complexes, when considering the properly forested coastline of slate using Fennoscandia at the Holocene Thermal Maximum (HTM).

Transference Hypothesis

Another important factor to consider when investigating the uptake of slate is its relation to the preceding and comparable industries of different raw materials. Clark (1979, p. 233) and *cf.* Broadbent (1979, p. 119) proposed that slate industries developed on the prototypic basis of already existing bone industries and suggested two components to the transition from bone to slate, either:

1. Transference: "slate working technology is transferred from bone working technology" or
2. Substitution: "forms of one medium are duplicated in another—often a material substituted due to the unavailability or high cost of the original".

These suggestions seem reasonable both in terms of (a) the very similar production process employed in crafting either slate or bone implements (sawing, snapping, grinding, *etc.*), (b) that the functional tool types made from bone and slate often overlap and (c) the limited range of raw material selection facing circumpolar maritime groups (*e.g.* wood and cryptocrystalline lithics). Although suggestion (1) seems most plausible, it does not provide the incentive for innovation or uptake of slate technology. Suggestion (2) may do so, for instance, if the availability of bone blanks was insufficient for meeting the requirements for tool production.

Such a scenario might be expected during times of population growth and economic specialization, whereby the increasing demand for bone tools typical of the Mesolithic (harpoons and bone points) would drive the innovation for alternative raw material strategies. As the availability of suitable bone blanks is limited by hunting and scavenging efforts, reducing the need for osseous material through including a comparatively suitable lithic resource (such as slate) could be a solution and provide the necessary incentive. The result would be a gradual separation of bone and slate tool types, prioritizing the more limited resource (bone blanks) for the most suitable function (harpoons, hooks and leisters), while experimenting with the more abundant resource (slate).

Considerations of tool use life/durability come into play in a technological transference. Making modifications to raw material and/or tool design may impact tool performance, which again affects the cost/benefit analysis in making technological adjustments/innovations (Bettinger *et al.* 2006, p. 541). In a transition from bone to slate tools, it seems likely that the use life of hunting vs processing tools was differentially impacted. Hunting tools are assumed to be more durable when made from the bone due to the brittle nature of slate points, while processing tools might have slightly longer use lives when made from slate as re-sharpening through polishing inflicts minimal mass reduction. Although applicable to both, this is particularly true of slate due to its massive composition compared with the fibrous internal structure of most bones. However, there might be other factors more important in driving raw material preferences in hunting tools, such as the desired shape and size of tools. Given the porosity and tubular construction of most bones, they may be less suitable for certain purposes when presented with slate as an alternative. The range of tasks that can be subjected to standardized (serial) production is more limited within the bone industry given the morphological diverse and heterogeneous qualities of individual bones compared with high-quality slate slabs.

Concerning the procurement phase, slate has multiple benefits over osseous material. Although outcrops of high-quality slate are rare, when first encountered, they provide access to large quantities of highly homogeneous raw material. In addition, the very morphology of slate is a technological affordance as the lamination and high fissility cause natural splitting along flat planes, ideal as easily workable preforms for slate tool production and ultimately perfect for standardization. All of these factors also hold in comparison with cryptocrystalline lithic alternatives.

Maritime Intensification Hypothesis

The general resource diversification of the Broad Spectrum Revolution following the eco-climatic conditions put in place by Holocene warming and disappearance of the megafauna has been suggested as a possible incentive driving slate tool innovation. For example, Ames (2009) suggested that slate technology followed the increasing diet breadth and inclusion of marine resources in early Holocene Alaska. The general sentiment of foraging theory has been that marine resources were only targeted systematically very late in human history and then merely as a consequence of reduced terrestrial resource packing (Binford 2001, p. 385). This might explain the post-glacial date of all known slate complexes globally.

However, there seems to be a strong "terrestrial bias" inherent to the assumptions of optimal foraging theory, devaluing marine resources. It has been claimed repeatedly that aquatic resources provide lower return rates compared with terrestrial alternatives. For instance, Osborn (2004, p. 146) states that "marine mammals should be added to the aboriginal diet as a function of the decreased availability and increased handling costs of lower-ranked terrestrial resources". Several potential research biases may contribute to a somewhat skewed terrestrial focus: (1) many of the prime coastal areas of the Palaeolithic are highly underrepresented in the archaeological record due to taphonomic factors such as eustatic dynamics and inundation causing coastal erosion. (2) The ethnographic record is skewed toward terrestrial populations as coastal areas have been more prone to early contact and displacement of HG's by historic state formations (Yesner *et al.* 1980).

Furthermore, there is the idea that the technical requirements for maritime resource exploitation are particularly high because it is associated with both increased technological complexity and diversity (Osborn 2004, p. 147) and that this may only be brought about by some significant push factor (B. Fitzhugh 2001, p. 151). This is a consequence of the front-loaded character of maritime technologies, in which the necessary investments for establishing positive return rates generally are much higher in marine than in terrestrial economies. Instead of a gradual increase in technological investment following a gradual increase in hunting success, marine hunting is thought to be characterized by investment thresholds. In contrast to terrestrial hunting technologies where, *e.g.* a stick becomes a spear that becomes an atlatl and so on, you do not gradually move from no boat to half a boat and eventually to a complete boat. Prior, front-loaded investments must be made in order to overcome the inherent threshold to get started and before gradual improvements can be made. Given the front-loaded character of many maritime technologies, slate technologies have frequently been expected to develop only under conditions of highly dense marine resources (seasonal packing), in terrestrially unproductive environments and with heightened human population numbers, as such conditions are thought to mitigate the high initial investment costs necessary to turn a profit.

This prediction is partly contradicted by the evidence from Arctic Norway. Although the period of slate uptake and dispersal in Norway corresponds to the forest maximum of the Holocene Thermal Maximum (HTM) with peaking terrestrial productivity, the existing faunal record, toolkit and settlement pattern strongly indicate increasing maritime focus.

Aesthetic Hypothesis

Non-functional properties of slate have also been suggested as explaining the uptake and great success of the slate industry. In Fennoscandia, there has been a long culture-historical tradition of using distribution maps of elaborate slate tools as a marker of migration and diffusion (Äyräpää 1950; Damm 2012; Gjessing 1953; Huurre 1983; Meinander 1964). In Norway, the aesthetic qualities of slate have been emphasized as important cultural and ritual signifiers (Auset 2007; Sommerseth 1997). That most attention has been directed at what potentially are high-status trade objects within the slate industry may follow from the occurrence of some particularly striking and highly elaborate slate daggers found across Fennoscandia: the carved animal-headed daggers, predominantly portraying moose (see Fig. 2). While not all slate daggers are of the elaborately carved type, this is a highly distinct tool type. Combined with the fact that unelaborate slate daggers and spear points are almost indistinguishable, this tool type has received the most attention. Despite their infrequency, the wide distribution of animal-headed daggers has been used to argue for a less exclusive marine association of slate tools and that the function of the slate industry may not be foremostly concerned with economic activities (Olsen 1994, p. 83). Although some such slate finds are known from the interior waterways of central Sweden (Baudou 1992; Broadbent 1979, p. 119; Lundberg 1997, p. 140) and Finland (ID: KM11703:1), reviewing the current distribution of slate daggers in Arctic Norway reveals a near-exclusive coastal provenance (n = 17). Importantly, decorated or elaborate slate artefacts are in general very rare in Arctic Norway, while seemingly more abundant on the central Norwegian coast of Trøndelag and southern Nordland counties, where various species adorn the carved slate knives, such as fish, whales and birds (*e.g.* Gjessing 1943, p. 404; Holdberg and Røskaft 2015, pp. 57–60). While carved parallels occur across most of the Late Stone Age (LSA) in the osseous industry, animal-headed slate knives appear to be limited to the early slate phase.

Claims of non-utilitarian uses of slate have been made, for instance concerning the "T-shaped artefact" distributed along the Gulf of Bothnia (Damm 2012, p. 236) and "ring ornaments" found across eastern Fennoscandia and Estonia (Ahola 2017, p. 211; Kriiska 2015, p. 113).[4] Even if granting non-functional purposes of these artefacts, they make for the odd exception. The slate industry at large is a technological tradition strongly oriented toward formal tools. Functional properties seem to provide more important reasons for uptake and evolutionary maintenance than its aesthetic characteristics. Although factors such as aesthetics, symbolic value and status of slate objects are highly likely to be part of the picture, I maintain that the adoption of slate technology cannot solely be driven by non-functional characteristics, as adaptive pressures acting on subsistence technologies select for functionally beneficial properties in the long run.

Evidence of Maritime Intensification and Correspondence with Theoretical Predictions

Based on the archaeological observation that slate technologies have a strong coastal distribution and the functional assumption that they are part of maritime adaptation, variation in the use of slate tools can be used as a proxy for maritime intensification. "Intensification" is here used in the *sensu lato*, systemic sense, of any input made to an economic system with the aim/result of increasing returns (Tainter 2006, p. 61). Intensification strictly defined entails increased labour efforts to maintain constant returns, typically by targeting lower-ranked and more time-consuming resources (Morgan 2015). Comparatively, systemic intensification does not have to result in a shift in the relative importance of, *e.g.* different foodstuffs or increased reliance on lower-ranked resources. It rather focuses on the total investment costs of a subsistence regime, independent of resource rankings.

It is necessary to establish what evidence there is for maritime intensification within Arctic Norway and its relation to theoretical predictions concerning the ecology/demography/technology link, derived from human behavioural ecology. The following review acts as a first high-resolution empirical case study for the investigation of the general drivers of innovation of slate technology and its place within the socio-ecological system that constitute maritime adaptations.

Ecodynamic Setting

Recent modelling of human population changes in Arctic Norway has demonstrated repeated boom-and-bust cycles corresponding to important changes in the biophysical environment (Jørgensen 2018). The most significant population boom-and-bust cycle occurred during the mid-Holocene, peaking at 6000 cal BP (Fig. 3).

Palaeodemographic modelling is based on the summed probability distribution (SPD) of large sets of radiocarbon dates, acting as a proxy for relative population size changes in the past. This is premised on the dates-as-data theorem, assuming a constant deposition rate of datable material per person. Thus, the number of dates per time unit is inferred to be equivalent to relative population size. The method has gained wide acceptance after the formative study by (Shennan and Edinborough 2007) and the

[4] Note that, although referred to as made of "slate", the ring ornaments are primarily made of metatuffite.

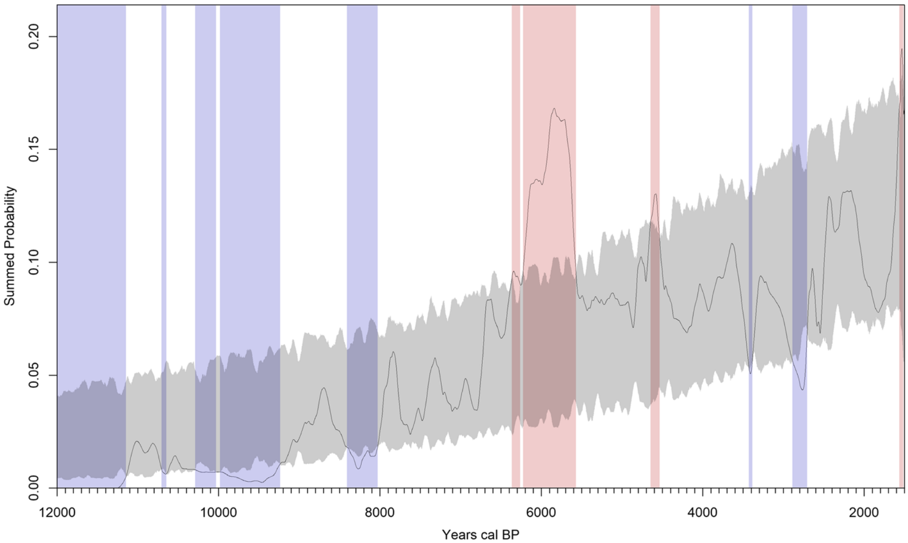


Fig 3 Palaeodemographic model of the population trajectory on the basis of ($N = 735$) dates from coastal sites in NW Arctic Norway (hatched area marked in Fig. 1). Red bars correspond to positive deviations from the expected exponential growth interval (marked in grey). Blue bars correspond to negative deviations. Consult online version for colour reproduction of figures

method has proven its usefulness through a number of rigorous tests (*e.g.* Edinborough *et al.* 2017). Result reliability is ensured through testing of statistical significance by use of simulated controls, available in the "R" statistical software (R Development Core Team 2015) using the Rcarbon package (Bevan and Crema 2018). The model presented here consists of ($N = 735$) radiocarbon dates form coastal sites in NW Arctic Norway. Auditing and binning procedures for this model are presented in the original publication of the radiocarbon dataset (Jørgensen 2018). Statistical significance testing of the model was done through 1000 simulation iterations of an exponential growth function, following the procedure in (Shennan *et al.* 2013; Timpson *et al.* 2014). This produced a highly significant global p value of 0.001 for the demographic model (consult SI for output data and result statistics).

Detailed scrutiny of the mid-Holocene population cycle and regional differentiation has demonstrated that it entailed considerable coastal packing and coincident population depletion in the interior (Hood *et al.* In press; Jørgensen and Riede 2019). A wider comparative study showed that the human ecodynamics identified in Arctic Norway occurred in synchrony with a maritime adaptive specialization across northern Fennoscandia (Jørgensen *et al.* 2020) along with analogous population dynamics in adjacent areas (Tallavaara *et al.* 2010; Tallavaara and Pesonen 2018; Tallavaara and Seppä 2012). This points to a striking relationship between the importance of ground slate technology for maritime purposes and human coastal population size.

Evaluation of the ecological setting and its relation to the population dynamics suggest direct climatic drivers of the long-term developmental trends (Jørgensen 2018). More specifically, the coastal population model and coastal environmental proxies indicate a demographic response to particularly productive conditions in the coastal/marine environment, as there is strong trend correspondence between local marine productivity proxies and demography (Jørgensen *et al.* 2020).

Crucially, the mid-Holocene population peak corresponds to what was also a forest maximum, with forest coverage on the coast, greatly exceeding current conditions (Sjögren and Damm 2019). In response, the presence of sedentary ecotype, forest reindeer close to the coast has been suggested and argued to have reinforced the coastal settlement packing (Hood In press; Jørgensen and Riede 2019). This would undercut the need for mobility patterns into the interior as all necessary resources were available at the coast and thus facilitate increased sedentism. Thus, the human ecodynamics of mid-Holocene Arctic Norway suggests maritime intensification.

Sedentism and Settlement Pattern

Sedentism and high population densities are common characteristics of mid- to high-latitude, maritime-adapted populations. Increased coastal sedentism and potential year-round coastal habitation seem likely in the Norwegian case, with mobility among coastal sites rather than between coast and inland. Previously, various forms of coast/inland seasonal migration have been proposed for the mid-Holocene (Engelstad 1984, 1985, 1988, 1989, 1990; Holdberg and Røskaft 2015, pp. 43–69; Simonsen 1975). The most up-to-date discussion of regional settlement pattern supports the notion of increased sedentism, increased packing and potentially year-round habitation at coastal sites (Hesjedal *et al*. 2009, p. 407). Major population packing at the coast is now supported by palaeodemographic modelling.

This trend is in line with that of larger spatial scales, with increased sedentism, cultural layer accumulation and intensified aquatic economies appearing across Fennoscandia. Such patterns are well established on the southwestern coast of Norway. From approx. 7000 cal BP sites contain house features along with thick organic deposits containing ground technology (both slate and sandstone) and fish line sinkers (Bergsvik and Hufthammer 2009; Bjerck 2008). Indeed, increased reliance on fish resources has been argued to occur across Southern Scandinavia < 9000 cal BP, inferred from faunal data, settlement patterns and hunting tools (Mansrud and Persson 2018; Ritchie *et al*. 2016).

A number of models have been developed to account for the mechanisms driving increased sedentism among maritime groups. The stability and abundance of coastal resources are important factors. In addition, the use of efficient transportation technology cut travel costs that allow greater sedentism as one can maintain a wide foraging radius while simultaneously return to basecamp (*cf.* Ames 2002, p. 35). This is due to the benefits of boats compared with travelling on foot, enabling greater holding capabilities, the ability to efficiently transport complementary task groups and increasing the number of foray trips per day (Ames 2002, p. 39).

The relation between reduced mobility and demography is well established. One important empirical finding from ethnography is that *sedentism increases female fertility*. This is due to the physical stress of high-mobility lifestyles that sedentism reduces birth spacing as well as multiple beneficial bio-social feedbacks (Kelly 2013, pp. 193–200, 211), well exemplified by the Neolithic demographic transition (Bocquet-Appel 2011; Page *et al*. 2016). What is more, it has been demonstrated that only small adjustments to the mortality rate among hunter-gatherers have massive implications for the population trajectory: > 20% mortality rate results in near-zero growth, while a < 20% mortality rate results in near-exponential growth (Boone 2002, p. 15). The emergence of larger and more permanent sites in coastal Arctic Norway during the mid-Holocene should indicate a more structured land use with antecedent reduction of travel costs, fueled by the intensification of marine resources. If so, this may have had important demographic implications.

The most pressing prediction to discuss in this context are the implications of the *Ideal Free Distribution (IFD) model and the reason for population packing*. Ideal free distribution models have proven powerful in predicting how organisms, including humans, distribute across space (Tremayne and Winterhalder 2017; Winterhalder *et al*. 2010). The general assumption is that (particularly in the setting of colonization) the highest-ranked area is prioritized—following the marginal value theorem and diet breadth model. Consequently ranked areas get filled up whenever the return rate of the primary patch falls below the threshold of average returns in the second-rated patch. This produces a dynamic of resource-dependent packing, consisting of a proportional relation between the number of individuals within a given patch and the amount of resources in the same patch, when movement between patches is unrestricted (Fretwell 1972), however, see Bettinger and Grote (2016). Therefore in an IFD, all individuals have similar success rates because the benefits of inhabiting the most productive patches are offset by packing—similar to the "habitat matching model" (Fagen 1987). In addition, the most productive patches will exhibit most continuous habitation, with abandonment of marginal areas in favour of contraction in prime patches following negative environmental perturbations.

IFD dynamics are difficult to demonstrate in prehistoric cases due to lacking data on absolute population sizes and densities, as well as on the quality of patches. However, 1500–1700 AD tax records among Sami populations in Arctic Norway (Finnmark County) contain direct demographic information of relevance (Hansen 2009, 2018; *cf.* Hood 2015). The settlement and mobility patterns of this period appear to be consistent with IFD models, acting as an ecological analogue for the archaeological data: While settlements in main fjords display continuous habitation throughout the recorded period, smaller sites located in what appears to be marginal fjord habitats are only inhabited when there is excess population dispersing from the core settlements. Although, an argument from ethnographic analogy, a similar mechanism/dynamic is expected for the mid-Holocene archaeological record that population/settlement packing occurs in the first place should indicate that some patches were significantly more productive than others. This is corroborated by the ecodynamics results demonstrating peaking environmental productivity in the coastal environment approx. 6000 cal BP.

In contrast to the IFD, if some start to defend territorial claims to patches, the result is an ideal despotic distribution (IDD). In these circumstances, some will be much better off by controlling access to the most productive patches (Fretwell 1972). It has been asserted that the only reason for hunter-gatherers to stop moving within an environment of evenly distributed resources is if every other patch has already been claimed (Freeman and Anderies 2012; Kelly 2013, p. 106). It follows that *initial, local scale sedentism encourages increased sedentism on a regional scale*. If only one group drastically increases the time spent in a high-yielding patch, it is likely to cause domino effects on regional population and mobility patterns (Kelly 2013:107). At the current level of archaeological visibility, there is no direct evidence for IDD territoriality or conflict during the period in question. The settlement pattern rather seems to fit the predictions of and IFD.

Zooarchaeology

The most direct evidence of maritime intensification would be high resolution and representative faunal records. Unfortunately, the conditions for organic preservation are highly unfavourable from the relevant period in Norway, and so we are unable to provide reliable inferences regarding changes in the economic importance of various species. Taken at face value, the existing mid-Holocene faunal record suggests a reliance on fish over sea mammals. Despite a host of issues related to taphonomy and representativeness of these samples, a reliance on fish is to be expected based on the stochastic demographic qualities of important sea mammal populations (harbour and grey seals), making large fish species a significantly more resilient resource in the face of harvesting pressure.

The only faunal record dated to the 6000 cal BP population peak where the complete taxonomic range has been preserved is at the Storbåthellaren coastal cave. Coastal seal species and small whales are present, yet cod bones overwhelmingly dominate the sample (Table 2). This suggests fish resources were of main economic importance at the site. A similar pattern is also supported by faunal assemblages from slightly younger habitation sites in Arctic Norway, where cod dominance in NISP ranges between 50 and 95% (Engelstad 1983; Hodgetts 2010; Martens *et al.* 2017; Olsen 1967; Renouf 1989; Schanche 1988, p. 156; see also Blankholm *et al.* 2020).

The fish fauna composition at the cave has been suggested to reflect a deep-sea fishing strategy targeting migratory cod, with the secondary species being a normal bycatch of such a strategy (Utne 1973, p. 48). The extreme reliance on cod was further investigated through morphometric analysis of cod bones in order to evaluate the importance of coastal versus migratory phenotypes. The results indicate large migratory cod, averaging at 100 cm in length and calculated weight averaged at 7.5 kg (Utne 1973, p. 45). This also supports the main occupation taking place during the late winter/early spring, when the migratory cod arrives at the coastal spawning grounds (Yaragina *et al.* 2011, p. 239).

Storage/Processing

Caching of resources is a strong proxy for sedentism, as increased investment in stationary storage facilities is a common risk-reduction strategy among circumpolar populations in the face of lean season shortcomings (Halstead and O'Shea 1989; Minc and Smith 1989; see also, Balbo 2015). This is because of the drastic seasonal

Table 2 Summary of the mid-Holocene faunal record from the Storbåthellaren cave

Storbåthellaren cave faunal record. LSA layer exclusively			
Class	Mammals	Fish	Birds
Nr of species within the class	16	13	37
Number of fragments per class	2034 (5.3%)	35,200 (92%)	1038 (2.7%)
Most significant species within the class	Seal (unspecified)	Cod	Great cormorant
Number of fragments of most significant species	365 (17.9%)	23,077 (65.5%)	135 (13%)

differences in high-latitude environments. Storage is a predicted outcome of the logistic mobility and delayed-return economy among collectors that perform bulk extraction and mass processing (Lewis R. Binford 1980).

The true importance of storage lies in its implications for subsistence strategies. In order to supply sufficient stores to last the lean season, long-term and large-scale storage of previously mass-harvested resources become a requirement. Yet, mass harvesting cannot be applied to any resource; it follows the variation in density, distribution, pursuit and processing costs for various resources. Mass harvesting mostly entails targeting lower-ranked resources, *i.e.* species with rapid reproduction rates and low parental investment in offspring, particularly resources that occur both in abundance and high densities, such as salmon runs, acorns or locust swarms. This is necessary to compensate for the reduced trophic returns and heightened processing costs of smaller-sized prey. Mass harvesting, bulk processing and storage are a way of changing the rank of resources, as the energetic return rates of many small animals and plants are density dependent (D. B. Madsen and Schmitt 1998).

Central place foraging models predict reduced return rates during the winter season, implying a reduction in the "effective foraging radius" and a dietary broadening compared with that of the more productive summer season—also when applied to northern coastal groups (B. Fitzhugh 2003, p. 108). Yet, the particular oceanographic conditions of the Arctic Norwegian deviate from this pattern. The permanently ice-free coast of Arctic Norway produce a different ecodynamics compared with any other maritime location of equal latitude (70°)—making the winter a season of opportunity more than a polar desert to be endured (however, a drastic reduction in visibility, increased storminess, *etc.* contributes to making the winter fisheries notoriously hazardous even today). The spawning season of the migratory cod in late winter (February–April) attracts large-bodied, high-trophic fish prey to the Arctic Norwegian coast in quantities that for all practical purposes would have been inexhaustible to any pre-industrial fishing community.

Tentatively, this is why storage facilities are not frequent at Artic Norwegian sites.[5] Instead, a different set of technologies of comparable function has been suggested. It has been proposed that the cave site was used for stockfish production (Utne 1973, p. 48), which would provide the means for mass harvesting and bulk processing. In Norway, there is to date no evidence of surplus production of aquatic resources throughout the Stone Age (*cf.* Engelstad, 1984; Renouf, 1986, p. 10). We simply do not know whether densely packed resources such as salmon runs were exploited due to the poor organic preservation, salmonid bones in particular, as well as lacking investigations of palaeoriver systems following dynamic hydrological regimes throughout the Holocene. However, mass processing and storage using passive technologies such as preservative air-drying of stockfish have deep roots in Norway (Perdikaris 1999; Star *et al.* 2017). The climatic conditions required for such preservation techniques are very

[5] Note that recent excavations of multi-phase habitation sites employing large-scale turf stripping and excavation outside/between habitation structures have been successful in identifying what appears to be storage facilities dating to the population peak period. External hearths and cocking pits have been interpreted as signs of aggregate food processing for a larger community/multi-family group, potentially the remnants of bulk processing and preservation of mass-harvested bounty through smoking and drying (Hesjedal et al. 2009, pp. 54, 303, 408–2099). In addition, pits dug down inside the house floor have been interpreted as internal storage units (Hesjedal et al. 2009, p. 30).

specific to Arctic Norwegian coast. Although archaeologically elusive, there is no apparent reason why leaving fish to dry by itself should not have been practiced already during the mid-Holocene.

Although tenuous, slate technology may be indicative of bulk processing. The argument for the uptake of slate technology in Alaska has partly been associated with the beneficial properties of lunar slate knives in efficient fish bulk processing (Graesch 2007). Functional differentiation between smaller lunar/boot-shaped knives for fish processing and larger angular/straight knives for mammal processing might be the case in Norway—yet is in need of use wear and biomarker analyses to be tested.

Fishing Equipment

Well-dated and finely grained seriation sequences of maritime hunting and fishing equipment would provide direct evidence for the changing importance of marine resources. A few sites contain osseous fishhooks and some typological patterns have been pointed out across the Norwegian/Russian Arctic (Kiseleva and Murashkin 2019). Yet, severe taphonomic loss undercuts the potential for any serious understanding of quantitative variation through time.

Lithic fishing implements provide better prospects in this regard. Fishline/net sinkers[6] are most readily found at Late Stone Age sites, with very few finds prior to the early/mid-Holocene transition. The general trend from the excavations of multi-phase sites is that sinkers are strongly associated with slate assemblages and the presence of house features. Sites whose occupation history span the Holocene and therefore also precede the introduction of slate technology, conform to this pattern, with no/few sinkers occurring before the construction of house features (Gjerde and Hole 2013, p. 323; Hesjedal *et al.* 1996, 2009, p. 415; Niemi and Oppvang 2018, p. 34).

Sinkers indicate intensified exploitation of marine resources, as they are part of a procurement strategy involving going out into open water to do deep-sea fishing. LSA sinkers are mainly of fist-size (mean width = 10.3 cm), round cobblestones primarily of granite-like material with one- or two-side notches for line attachment. Figure 4 maps the weight distribution of 180 LSA sinkers, plotted against functional weight:depth ratio in line fishing (data in SI Table). It suggests that most sinkers were used for intermediate depths (30–40 m), yet with a considerable tail toward deep-sea fishing. However, the strength of currents may be as important in determining sinker properties as depth. Even deep-sea species like halibut of 100 kg are successfully caught in shallow waters (10–20 m). Preliminary investigation of the later period (Iron Age) sinkers suggests reliance on much lighter sinkers (*cf.* Helberg 1993, p. 177).

There is currently no reliable evidence of net technology at any point in prehistory in Norway. This is in contrast with sites in Denmark, Finland and Alaska, where large numbers of sinkers found together have been taken to indicate the use of nets. The positive identification of net technology in adjacent areas, such as the early Holocene "Antrea net" from Karelia (Miettinen *et al.* 2008), may increase the probability that nets were employed in Arctic Norway. But, the fact that sinkers mostly occur in small numbers per site in Norway goes against their interpretation as net sinkers.

[6] Fish line and net sinkers are not systematically separated in the literature and are therefore treated as one category under the term "sinkers".

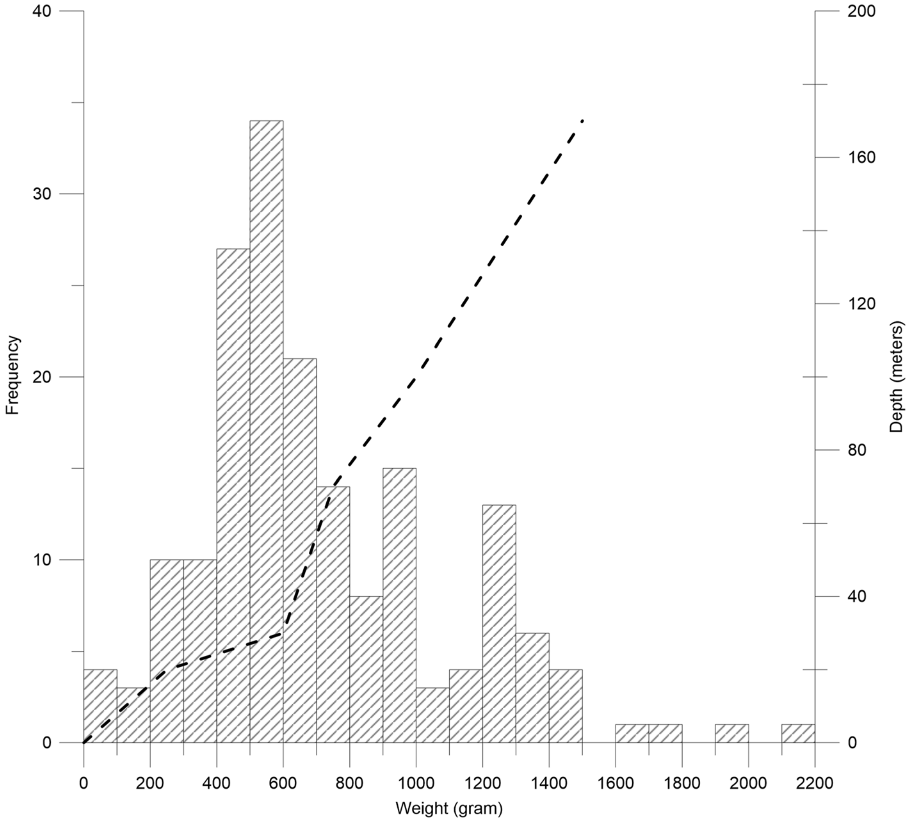


Fig 4 Weight distribution of $N = 180$ sinkers found alongside mid-Holocene slate assemblages. 100-g bins. Plotted against ideal weight:depth ratio for line fishing. See also data in Andreassen (1985, p. 217), Simonsen (1996, p. 185) and Utne (1973). Produced in Grapher 12

Rock Art

Arctic Norway hosts a spectacular UNESCO record of hunter-gatherer rock art in the Alta fjord, which uses a proxy for changes in adaptive strategies through time. The relative proportion of various animal taxa being depicted in rock art does not represent a realistic representation of their economic importance through time. Depictions of concrete subsistence technologies, however, may be more informative. In particular, boats provide a telling case of temporal change, as boat motifs are common throughout most of the Holocene. Boat depictions dated to the height of the population peak period are larger and contain more people compared with earlier boat depictions, occasionally with leading figures (*cf.* Olsen 1994, p. 84). Interestingly, a hiatus in boat motifs has previously been noted (Helskog 1985, p. 85). Recently, this has been corroborated, suggesting a complete lack of boat motifs during the mid/late Holocene trasition (Gjerde 2017; Helskog 2012). Precise dating is an issue, yet the suggested timing of the hiatus is 4700–3700 cal BP. This corresponds to a period of reduced demographic signal following the population decline on the coast (see Fig. 3) (E. K. Jørgensen 2018). This correspondence might suggest density-dependent factors at play in the construction and use of larger boats. Depictions of mundane, marine economic activities are not very common, as most apparently depict ritual/communal boat activities (*cf.* Gjerde 2018) (Fig. 5). This might explain the low frequency of particularly sea mammal hunting and to some extent fishing scenes.

When taken together, the human ecodynamics and adaptive evidence presented in this section point to a distinct intensification of coastal ecosystems and an increased adaptive focus on maritime resources, summarized in (Table 3).

Materials, Methods and Technological Predictions

The evidence for the maritime intensification and its relation to coincident changes across multiple human ecodynamics parameters is rather strong. In order to evaluate the importance of the slate industry to the maritime-adapted population in Arctic Norway, multiple lines of evidence were assembled. Data were sourced from the direct study of a large set of slate assemblages, curated by the Arctic University Museum, Tromsø, Norway. The intention is to provide a systematic and dynamic reconstruction of major quantitative and qualitative changes in the overall slate technocomplex. The most important empirical prediction to be tested is that the slate industry would initially be characterized by experimentation and high type variability with gradual specialization and reduced variability. This is to be expected from the mechanisms driving innovation and diffusion of technological knowledge, as identified by cultural transmission theory and innovation studies (O'Brien and Bentley 2011).

I performed a dynamic technological analysis of complete slate assemblages throughout the geographical area and tracked temporal changes. Particular attention was payed to the production sequence of various slate technologies. More detailed morphometric analysis and results will be published elsewhere.

Prior to this study, some coarse developmental trends had been suggested for the Arctic Norwegian slate industry. These also form predictions to be tested here:

- That slate technologies have considerable time depth in the Arctic and often formed the basis for chronological parallels to Neolithic trends in southern Fennoscandia (Simonsen 1976, pp. 144–146). With the advent of absolute dating methods and

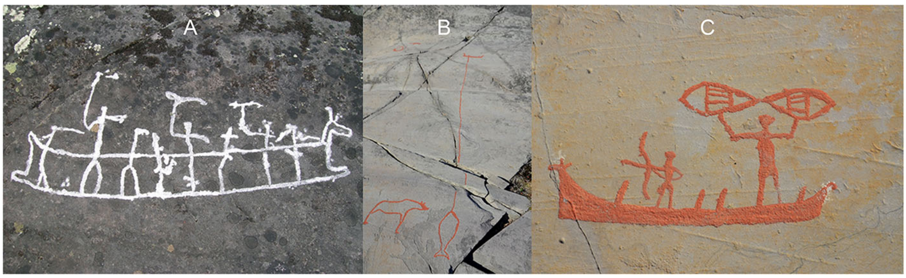


Fig 5 Rock art depictions of pre-decline boats and marine hunting activities. Boats are regularly displaying moose figures at the prow and with multiple human figures. **a** Boat carrying approximately seven human figures, some of which are holding objects on unknown nature. **b** Depiction of deep-sea fishing. A halibut has been caught on the line which is connected to the boat and human figures in the upper section. **c** Boat carrying two human figures, one apparently hunting at sea with bow and arrow and the other holding an object of unknown nature. Photos: Alta Rock Art Museum (CC BY-NC-SA 4.0). Collage and editing by the author

Table 3 Summary of human ecodynamics trends of the mid-Holocene as discussed in the text and the related evidence for maritime intensification during the slate period

Variables	Summarized evidence	Reliability of evidence
Demographic trend	Significant population growth indicated by palaeodemographic modelling.	High
Environmental setting	Increased environmental productivity demonstrated by a host of high-resolution, local palaeoenvironmental reconstructions. Local fjord productivity increases in tandem with maritime intensification among the human population.	High
Settlement pattern	Increasing coastal sedentism and site size indicated by numerous coastal habitation sites and the establishment of permanent housing features in organized clusters at the coast. Archaeological evidence of interior habitation reaches minimum in synch with coastal packing. Reduced mobility, strong coastal clustering and increased population density in line with IFD predictions.	High
Zooarchaeology	Faunal data indicate the primacy of fish over mammal dietary contributions. Also consistent with expectations derived from population ecology and risk reduction. Species composition indicates a strategy targeting high-trophic, deep-sea fish species.	Medium
Storage and bulk processing	Procurement and mass processing of packed resources is weakly inferred from slate processing tools and potential evidence of storage facilities. Insufficiently established due to lacking organic preservation.	Low, inferred
Fishing equipment	Increasing the number and distribution of line sinkers suggests increasing reliance on fish resources. Increasing the size of line sinkers indicative of deep-sea fishing.	Medium
Boat technology	In the absence of preserved boat remains, rock art depictions of larger vessels carrying multiple people suggest skin-covered, umiak-like, boat technology.	Likely, inferred

accumulation of slate assemblages, this timeframe has informally been adjusted to approx. 7000–3000 cal BP.

- Both percussive and sawing techniques were used in tool production (Simonsen 1996, p. 139).
- Percussive production techniques were apparently only in use during the initial phase (~ 7000 cal BP) of the slate complex (Hesjedal *et al*. 1996, p. 174; Sommerseth 1997, p. 38). This is based on the very limited occurrence of the Slettnes type projectile that, under scrutiny, seemingly was produced from a side-flake taken off a slate block by direct percussion and then trimmed bifacially without any traces of grinding.
- It has been asserted that the Arctic Norwegian archaeological record indicates a miniaturization process by which slate tools become smaller with time (G. Gjessing 1942, p. 321; Simonsen 1976, p. 281). Simonsen remarked upon a drastic reduction and a "degenerate" state of the slate industry in the final phase (Simonsen 1961, p. 485). Particular focus has been directed at the so-called miniature knives, defined as any single-edged knife < 8 cm long (Simonsen 1996, p. 146). The assumed development from large to small knives between 6000 and 4000 cal BP was superficially discussed by Andreassen (1985, p. 136), claiming there was nothing to this trend.

- That the fluted Sunderøy type point was a late development, but with a widespread dispersion of across northern Fennoscandia (Rankama 1986).
- That single-edged knives seem to supplant double-edged knives through time (Engelstad 1983).

None of these trends has previously been tested or controlled contextually and temporally—let alone systematically reviewed across a large sample of dated assemblages spanning the duration of the slate tradition. Production sequences are particularly poorly understood, as slate debitage has previously not been studied. This is partly because slate assemblages are prone to a certain set of biases, previously unexplicated in the literature. First, several classic slate assemblages were excavated prior to modern standards and many lack absolute dates. Slate assemblages without contextual control or dates are left out (*e.g.* the Larseng site, possibly the richest known slate assemblage in Norway (Simonsen 1956, p. 53)). Second, there is the issue of important sites for which some dates have been made at a later stage but the excavators did not collect debitage (like the classic Gropbakkeengen site) or did not record debitage stratigraphically (*e.g.* at the Gressbakken sites) (see Simonsen 1961). This undercuts the possibility of consistent investigations of production sequences, as most reports focus on complete artefacts. Third, it is a general problem that the majority of slate artefacts in the museum collection are stray finds from undocumented contexts, *e.g.* collected by local landowners from plowed fields. Until recently, these factors thwarted a systematic study of the slate industry.

Slate Abundance Index

Testing the correlation between population and technological dynamics, a "slate abundance index" (SAI) was constructed. Through tracking the relative proportion of slate artefacts and debitage frequencies relative to that of other lithic raw materials through time, the index is then compared with established palaeodemographic models in the area. The data set consists of 65 reliably dated lithic assemblages, compiled from published records (listed in the SI). Data is primarily based on site summaries of debitage from multiple and contemporaneous contexts which produced > 322,000 lithic objects. This significantly expands on previous indexes (E. K. Jørgensen *et al.* 2020).

Data was primarily collected from development-led excavations of large, multi-phase coastal sites. They provide the largest lithic assemblages and arguably the best representativity as the multi-phase sites may more accurately track changes through time than a collection of single-phase sites of wide spatiotemporal distribution. Here, both site types are combined to make the most extensive and complementary data set as possible. This is also important in adjusting for the variable degree to which slate debitage has been collected and meaningfully recorded. Although assemblages recovered prior to modern excavation standards are included in the SAI, their minor quantitative contribution is considered insufficient to significantly skew the results. The major bulk of data stems from recent excavations that consistently report debitage.

Most assemblages are directly radiocarbon dated. However, the oldest sites rarely produce datable material and are occasionally dated through shoreline displacement rates. This is feasible given the well-studied dynamic between isostatic uplift and shoreline displacement in Arctic Norway. Only coastal sites are presented here. Inland sites are not relevant to this comparison as interior slate use was minimal and inconsistent. Important interior sites have been mapped for reference and can be consulted in the Supplementary Information.

The average frequencies presented in the SAI are attributed to specific prehistoric phases as defined by the existing chronological framework (see Hesjedal *et al.* 2009, p. 379). The average frequencies therefore represent the mean ratio of lithic assemblage composition within the timeframe specified by the respective phase. Although it would be preferable that each assemblage was plotted based on its actual radiometric date span for maximum resolution, data reporting standards do not allow consistent and more fine-grained subdivision than at the level of chronological brackets. I maintain that the SAI still provide insight into long-term trends, sufficient for our purposes here.

Variability Indexes

Several indexes were produced in order to determine temporal variation and internal dynamics of the Arctic Norwegian slate industry.

A measure of temporal variation in slate "assemblage composition" was constructed on the basis of the ratio of knives-to-projectiles, based on 17 assemblages and compiled from published records (data in SI). The ratio was calculated using the functional ascription of knives and projectiles reported in the published records. Although some misclassification within reports and inconsistent classification between reports likely occur, the clear and intuitive difference between knives and projectiles in next to all cases do not merit the efforts necessary to reclassify the entire slate collection.

Assemblages were chronologically classified as either early or late. A classificatory separation date was set to 5000 cal BP, as this is an approximate midpoint in the duration of the slate industry. This ratio is informative of the technological priorities within the slate industry and helps identify what selective pressures might have been most effective in steering the slate industry. Although difficult to calculate precisely due to large differences in documentation standards and cataloging, the general trend is informative as these are large assemblages covering the entire slate using period. In order to counter spurious patterns, separate calculations were made for the ratio using only formal tools, as well as a combined calculation of formal tools and tool fragments (in cases where fragments were reported).

The evaluation of "assemblage variability" relies on qualitative observations made while studying slate assemblages first hand. This particularly concerns production and reduction sequence data, raw material quality, semi-structured weighing and measuring of debitage, miniaturization and typological issues. Working toward quantification of the qualitative evaluations constitutes an important avenue for future research.

Results

Abundance Index The results of the "slate abundance index" (Fig. 6) demonstrate that the use of slate was intensified sometime prior to 7000 cal BP and became the dominant lithic industry by 6000 cal BP. By this time, slate concentration often reached up to 80% of coastal site assemblages. A shift away from slate takes place at approximately

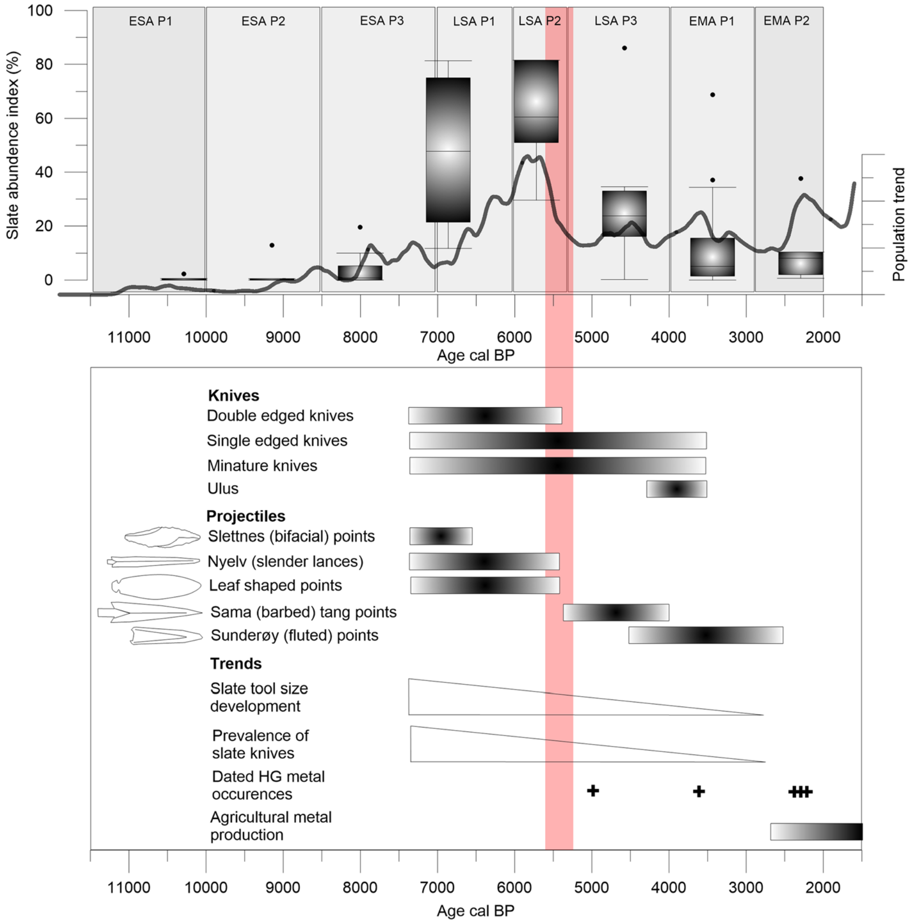


Fig 6 Upper section—the slate abundance index (SAI) mapping the relative proportion of slate, based on the frequency of raw materials in selected site assemblages plotted against the coastal population model of NW Arctic Norway. The SAI is presented as a box and whisker plot, with outliers given as dots. Most of the outliers constitute assemblages that are difficult to ascribe to one particular period, as they mostly date to the intersection between two periods. Grey blocks correspond to prehistoric periods of the Northern Norwegian chronology as data was collected period wise. Abbreviations at the top name the chronological periods: ESA, Early Stone Age; LSA, Late Stone Age; EMA, Early Metal Age. Lower section—illustration of typological changes and trends in Arctic Norwegian the slate industry, plotted against the patterns of demography and overall slate use. Metal data based on dates presented in Hood and Helama (2010), Jørgensen (2010) and Sundquist (1999). The red vertical bar marks the timing of the demographic downturn. Produced in Grapher 12

5300 cal BP, judging from the inventory of securely dated key sites. Interestingly, the pattern of slate use corresponds to the population development on the western coast of Arctic Norway—displaying marked population growth between 7000 and 5500 cal BP, terminated by an abrupt population decline. Slate is still important for some time after the 5500 population downturn, judging by the presence of formal tools, but the slate component is reduced from 70–80% to about 30%. This is significantly more drastic than previously thought (Simonsen 1996, p. 137). An expedient technology based on local quartz takes over quite immediately, with a dominance of 70% by the LSA period 3 (5500–4000 cal BP).

The results of the SAI confirm the prediction that the slate industry should be characterized by high initial experimentation rates with increased standardization through time. The greatest variation occurs in the LSA P1 and subsequent reduction of variation.

Shift in Production Technique The results from reviewing a large set of slate assemblages containing debitage suggest important changes in the slate production technique through time. This review identified two technological regimes within the slate complex, henceforth termed Early and Late slate phases (Fig. 7). The timing for this shift appears to correspond to the overall demographic trend. Despite being a gradual development, it centres on 5000 cal BP with the disappearance of important tool types dependent on percussive techniques.

Initially, very large quantities and specimen size of slate debitage resulting from percussive reduction sequences dominate. Debitage is massive, often > 10-cm-large flakes. However, more fine-grained sawing and production of standardized, rectangular stick blanks also occur in the early slate phase, as indicated by the very standardized Nyelv points but also observed directly in the debitage from early dated contexts. Most significantly, the early slate assemblages are characterized by a wide variety of working techniques. This is well exemplified by Normannsvika house 1, in which the majority of the slate assemblage is clearly worked by percussive reduction, possibly by a combination of direct and indirect techniques, with secondary, bifacial trimming—along with sawing and grinding by way of the so-called chocolate plate technique.

This variability was not observed in late slate assemblages. Instead, late phase slate assemblages are remarkably consistent in the almost complete reliance on sawing and grinding, with minimal evidence of percussive techniques beyond initial reduction. An ideal example representative of the terminal phase assemblages is the Kilden site, a totally excavated site with intact stratigraphy, dated 3800–3000 cal BP (Hesjedal *et al.* 2009, p. 159). It contained a high number of projectile points, of which all identifiable specimens were very small and highly standardized fluted Sunderøy type points (complete, n = 27 + fragmented n = 70). The raw material is a very homogeneous

Fig 7 Illustration of debitage from the two reduction sequences characterizing the early and late technological regimes. Early: primary reduction of a slate block with distinct traces of and debitage from percussive reduction. Large and coarse-grained material. Late: homogeneous and small debitage from sawing and snapping showing traces of the chocolate plate technique. Small insert photo: magnified view of a sawing furrow. Note the parallel sawing marks on the slightly angled cross section and the characteristic “lip fracture” at the dorsal side, which arises from snapping before sawing is complete. Such lip fracture features can also be seen in some of the debitage to the right. Credit: Author

high-quality slate, while the debitage consists of very small (< 2 cm) mostly rectangular fragments. The production technique is limited to sawing, focusing on highly standardized (apparently serial production) of rectangular stick blanks made from what initially were thin slabs. Identical assemblages with corresponding dates are found at Sandbukt house 21, Studentervika B14 and Skjærvika S44 (Henriksen and Valen 2013, p. 256; Simonsen 1996, p. 65; Thommessen 1994). It is instructive that slate knives are altogether lacking from these sites, yet knives made from quartzite do occur (Skjærvika S44). This underlines the priority of slate projectiles over knives in the final phase.

Upon review of the debitage, it became apparent that the chocolate plate production technique consistently produced cross-section edges of a 100–120° angles. Such cross sections often contain parallel striation marks from sawing usually visible through a magnifying lens (see Fig. 7). As the production often ends with snapping of plates into individual parts before sawing completely penetrate the slab, the snapping produces characteristic “lip fracture” features on the dorsal side. Both the cross-section angle, striation marks and lip feature are particular to sawing production technique and provide valuable diagnostic traits.

The set of qualities characterizing the early and late slate production regimes identified here seem to be directed at different operational goals. The early slate phase being predominately a “skill-led production”, while the late slate phase prioritized “production-chain efficiencies”. This is indicated by slate tools being more elaborately made during the population peak (early slate period), while production efficiency is taken to its extreme through the late phase chocolate plate manufacture process and standardized mass production of Sunderøy type projectiles.

Furthermore, there is a trend toward reduced variability through time in tool types as well as the quality of raw material. Slate raw material variability is much higher in the early phase, consisting of significant variation in quality, resulting in a lower potential for standardized production. Combined with changes in production techniques, these trends might reflect local experimentation with various types of slates in the early phase, while distributive networks channelled the high-quality slates after identification of suitable extraction sites (quarries) that seems to characterize the later slate phase. If so, this might account for the more efficient and restrictive use of slate in the later phase. Alternatively, technological demands for a particular quality of raw material can also result in reduced demand. It is currently not feasible to determine whether change in technology drove demand for smaller amounts yet more homogeneous raw material or whether the technological change was a response to reduced access to slate sources (*cf.* Nyland 2017). Future research into the provenience of slate sources and excavation at quarries should mitigate this.

Weighing of slate debitage from different dated sites was attempted to test whether the exploitation degree per unit slate was actually higher in the late phase. However, collection biases thwarted this attempt because slate debitage has been subject to very variable documentation standards through time (not collected at all in the early twentieth century). In addition, there is a bias that grinding and sawing techniques potentially produce very limited debitage. Procurement strategies of slate also influence debitage composition, for instance, if primary reduction and preparation of slabs and blanks were performed at quarry contra habitation site. Mapping the staging of reduction sequences should be pursued in future research.

The results of the production sequence analysis correspond to the prediction of high initial variability in production chains and tool types, as well as the predicted reduction of variability through time.

Assemblage Composition The result of the assemblage composition comparison is presented in (Fig. 8) and general trends are given in (Fig. 6). The general trend confirms a development from higher knife ratios initially toward a significantly higher ratio of projectiles in the late slate phase. In the early period, there is on average a > 2:1 dominance of knives over projectiles. In the late phase, this is radically different, with an approximate 1.5:1 dominance of projectiles over knives. The trend is consistent regardless of the calculation procedure (complete tools) or (tools + fragments). This ratio is also an indication of variability, as the range of variation in the knives:projectiles ratio is very large in the early phase and drastically reduced in the late phase. Interestingly, the reduced variability appears to be a strictly chronological phenomenon, as opposed to the initial assumption that site function would be the main driver of intrasite slate tool variability.

These results are backed by the qualitative review of slate assemblages, as a strong trend toward fewer knives and predominance of projectiles was observed repeatedly across sites. However, the estimated ratios are likely inadequate for tracking the actual magnitude in difference, due to great variation in reporting standards in published records. These results could be driven by multiple confounding factors: (a) a shift in settlement patterns or site functions, (b) different deposition rates, as knives might be disposed of at site while most projectiles might be lost while out hunting, (c) a shift in production technique, whereby caching of mass-produced projectile points are more

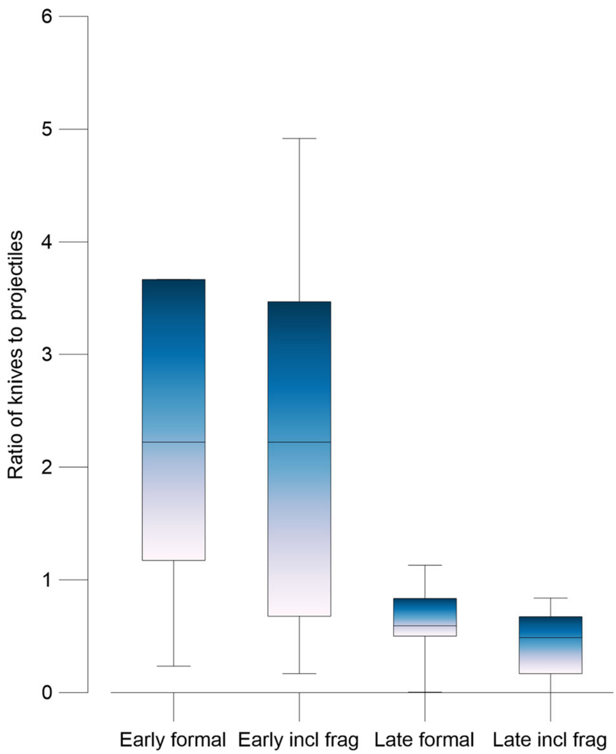


Fig 8 Box and whisker plot of slate knives-to-projectiles ratio based on 17 assemblages, classified as early and late industries. Plotted using the interquartile range factor. Produced in Grapher 12

readily uncovered in the latter phase than the more varied production sequence of the early phase. Still, I suggest the result may be indicative of true changes in the organization of the slate industry across time.

Type Variability Mapping of type variability confirms a trend toward reduced variation in tool types through time. The pattern emerging from the qualitative evaluation of the tool assemblages conforms to the prediction that the initial innovation period produced high type variability that gradually reduced through time—likely as various selective pressures reduced the number of tool types toward the most successful variants.

This is well exemplified by the contested issue of miniaturization. The current review confirms a general trend toward miniaturization, however not in the previously expected way. "Miniature" tools, such as knives and adzes that were thought to be typical of the late phase (Munch 1962. p. 20; *cf.* Hultgreen 1988, p. 92), are commonly found in the early slate period as well. However, the general tool size does decrease with time. The tools of the early slate assemblages are generally large. In fact, large slate tools are highly infrequent in the late slate phase. Yet, the early assemblages are more diverse than previously recognized. The large slate assemblage from the Sandbukt site seems to support this proposition, with a much larger and more diverse slate toolkit at the higher elevated (*i.e.* older) settlement area (group A) that also contained 7 times the number of miniature knives compared with lower elevated (*i.e.* younger) group B area (Simonsen 1996, p. 149).

Very large spear points of the leaf-shaped type (7000–5000 cal BP) disappear and are supplanted by tanged and barbed points (Sama type) of medium size (5000–3500 cal BP), while the late slate phase seems to lack both and is instead marked by the very standardized production of small Sunderøy projectiles (4500–2500 Cal BP) (*cf.* Hesjedal *et al.* 1996, p. 176). Further underlining this trend, lance points (Nyelv type) apparently disappear by 5300 cal BP.

The concomitant loss of large double-edge (DE) knives and large leaf points is instructive. Assessing such artefacts indicate previously unrecognized patterns of reuse and multifaceted use lives. Several DE knives appear to have been worked into leaf-shaped points (or the other way around) by reworking the base/proximal end. Actually, there are very few clear-cut cases of DE knives compared with what is stated in the catalogues. Tentatively, this coincidental pattern is the result of a shared production sequence. The late slate phase appears to have a stronger separation between the initial production sequences of knives from projectiles and may suggest a reason for the priority of projectiles.

The implication of this trend is not clear. Assuming that large knives, spears and lance points are specialized equipment for sea mammal hunting, their disappearance might indicate reduced importance of such activities. This necessitates further investigation and comparison with osseous industry and faunal data. If the trend of miniaturization is taken at face value, it may echo arguments concerning the functional differentiation between slate processing tools on the Pacific Northwest coast, suggesting that smaller knives were employed in fish scaling and processing (Hayden 1987, p. 41).

However, there is the problem of re-sharpening in slate knives and mass reduction through extended use life. That more miniature knives occur in some periods than others could reflect the intensity of use, an effect of increased acquisition costs of raw material following, *e.g.* increased sedentism (Pargeter and Shea 2019). The opposite effect seems more likely though, as the intensity of use is expected to incentivize greater investments in that particular tool type.

Slate Supplanted by Metal An uneven phasing out of the slate industry was identified when reviewing the contextually controlled slate assemblages. Slate knives disappear sometime 3500–3000 cal BP while projectiles remain slightly longer, approx. 2500 cal BP. The abandonment of the slate industry and its relation to alternative technologies able to supplant slate was investigated by reviewing dated metal finds and correlating them with the dynamics of the final slate phase—plotted in (Fig. 6).

The evidence for metal technology, either imported or locally produced, is scant. The introduction of metal production occurred with the Germanic agricultural expansion approx. 2500 cal BP (Jørgensen 2010; Sjögren and Arntzen 2013; Sundquist 1999), which seemingly corresponds to the termination of the slate industry. This is in support of earlier proposals that metal displaced lithics between 3000 and 2000 cal BP (Olsen 1984; Sundquist 1999, p. 49; *cf.* Hultgreen 1988). Technological displacement should explain the final disappearance of the slate industry, as iron technology is also taken up by the respective hunter-gatherer population at a corresponding time.

Notable examples are the carved bone/antler knife handles with rust stains dated 2500 cal BP (Olsen 1984; Solberg 1911), and the ulu-shaped[7] iron knife blade from a grave also containing asbestos ceramics and slate (Sundquist 1999, p. 47)—typologically dated approximately to the same time. In addition, there are two cold-hammered copper tools that overlap with the final slate phase and associated with late (Sunderøy) slate points (Gjessing 1935, p. 39; Hood and Helama 2010; Olsen 1994, p. 125).

Pre-iron metal objects are known from some sites dated < 3500 cal BP, as part of a Bronze Age agricultural expansion, yet only in the southern region of the study area (Johan Eilertsen Arntzen 2013, 2015; Bakka 1976). This differs from the cold-hammered copper that is characteristic of Sami sites from approx. 2000 cal BP and into the Medieval period (Hesjedal *et al.* 1996, p. 184). In fact, only a few finds of copper implements are known from HG sites prior to the spread of iron technology—the implication of which has been debated (Olsen 1994; Schanche 1989, p. 63; *cf.* Hood and Helama 2010). The quantity and character of these implements suggest sporadic import, rather than local production. However, metal has been identified at the Bolshoi Oleni Ostrov burial site on the Kola Peninsula, dated to 3500 cal BP (Murashkin *et al.* 2016). Considering other similarities in material culture make it likely that metal circulated into Arctic Norway and acted as a technological alternative supplanting slate—likely due to the reduced production/procurement costs and increased reliability. It has been argued that, in general, the supplanting of lithics by metal follows the higher plasticity of metal as well as providing longer/sharper edges than lithics implements can provide (Manclossi *et al.* 2019, p. 1314)—in line with the original arguments for adopting slate over cryptocrystalline materials.

[7] This object (Ts2004) may be better understood as ulu shaped, rather than mimicking the southern Scandinavian bronze tradition, as originally proposed. See https://www.dokpro.uio.no/perl/arkeologi/visetekst.cgi?DATABASE=Ts&KRYSS1174%40=on.

Discussion

So far, I have presented various empirical trends and theoretical predictions pertaining to the Arctic Norwegian slate industry. Here I return to generalizable properties of slate technology by discussing three middle-range issues in consecutive order:

1) Why slate technology appears to be a particular maritime success?
2) What causal contribution slate technology makes to the population-scale adaptive success?
3) Why it became of less importance and was ultimately abandoned?

Why the Adaptive Success of Slate Technology in Maritime Settings?

It has been claimed that technological innovation primarily is a risk-reduction response to stress (B. Fitzhugh 2001). This seems to be the case for the PNW slate industry. Climate cooling that reduced the abundance of marine mammals and led to a turn to lower-ranked fish resources has been proposed as the reason for slate innovation in Alaska. However, the innovation history appears to be the direct opposite in Arctic Norway, where the adoption and dispersal of slate technology coincided with highly favourable eco-climatic conditions and population growth. Given a different evolutionary history of the circumpolar slate industries, what is the common driver of success?

This question becomes all the more pertinent considering that marine mammal hunting (in its many forms) for direct, dietary purposes can be successfully executed with implements made of bone, wood or most sorts of lithics depending on delivery system (projectile points, spearing, clubbing, nets, *etc*.). Instead, I suggest that slate implements become particularly advantageous when integrated into a specialized maritime technocomplex and for reasons that are not relevant in terrestrial settings. This is inferred from the specific culture-historical setting of the Arctic Norwegian slate industry:

The introduction of slate technology to the area coincides with other noticeable technological events. Ceramic (Early Comb Ware, henceforth ECW) and bifacial lithic technologies were introduced > 7000 cal BP to easternmost Arctic Norway (Fig. 1) from a terrestrial setting in adjacent areas to the east (see Skandfer 2005, p. 19).[8] This event corresponds to a pulse of inland activity (Hood *et al*. In press: Fig. 19.1-2; Jørgensen and Riede 2019: SI Fig. 1). Both the ceramic and bifacial technologies drop out of use in Arctic Norway by 6500 cal BP (Damm *et al*. 2019; Skandfer 2009). Slate, on the other hand, takes on a completely different level of importance after reaching the Arctic Norwegian coast where it seems to trump any importance it had in the Finnish Mesolithic. The apparent lack of slate debitage at ECW sites supports this dynamic and dispersal pattern, as the slate artefacts found in association with comb ceramic appears to be imported as complete tools (Hood 1992, pp. 495–507). In addition, ECW sites frequently contain woodworking tools such as adzes made from slate. These are

[8] However, the time depth and origin/dispersal of bifacial technology in the area is not properly accounted for. The very old age of bifacial points in Arctic Norway (Hesjedal et al. 1996, p. 167; Skandfer 2005, p. 16) deviate markedly from the general spatiotemporal dispersal pattern across Eurasia, as mapped in (Darmark 2012, pp. 274–276).

directly comparable with Suomusjärvi tools and are hardly found elsewhere in Norway. This suggests that the initial slate industry was developed to solve a different set of problems in southern Finland than what evolved on the Arctic Norwegian coast. [9] Apparently, there are important niche-specific differences in selective pressures driving technological innovation and adaptive strategies in arctic marine contra mixed boreal biomes. However, what crosscuts slate using *maritime groups* is the need to mitigate the particular risks that follow increased sedentism, heightened population packing and resource depletion.

As such, there are specific selection pressures acting on different stages of the slate production sequence that apparently are particular to maritime economies. As discussed initially, I assert that the combination of high formability and potential for standardization makes slate the ideal resource for making replaceable implements. Replaceable parts are advantageous in that it reduces the cost of maintaining multi-component tools. Aquatic technologies are almost universally multi-component and have on average a higher number of technounits per subsistant, used as a measure of tool complexity (Torrence 1983). This is mostly the case for projectiles/hunting tools, where swift replacement of broken implements is made possible through standardization of for instance projectile width and hafting and re-sharpening of broken points (Grønnow 2017, p. 47). Both are important when hunting on water.

Slate knives, however, are primarily beneficial through their processing qualities when integrated into a technocomplex directed at marine mammal exploitation for *indirect*, non-caloric procurement, purposes—that is, skins as the targeted resource. Non-dietary uses of the slate may be a decisive factor in its adoption, similar to the "secondary products revolution" argument in Neolithic research (Sherratt 1981, 1983; *cf.* Marciniak 2011). A similar argument concerning the value of the secondary product of seal hunting has been proposed for Dorset Palaeoeskimo of NW Newfoundland (Renouf and Bell 2008). Based on the technological results, it seems likely that slate knives were initially developed for increased efficiency and reliability of skin processing. Later, more angular and smaller slate knives dominate, which, by analogy to Alaskan slate knives, appear to be related to the mass processing of fish. Angular and semi-lunar slate knives are present in the early slate phase but become the dominant form in the late phase.

Ethnographic and experimental accounts underline the vital role of secondary products to northern maritime groups. This is particularly driven by boats as "instruments of production" which is the main mechanism for responding to the maritime risks and opportunities mentioned above (Ames 2002, p. 20). Furthermore, the use of efficient transportation technologies changes the game in favour of maritime adaptations by increasing the net productivity of aquatic adaptations (Ames 2002, p. 22; see also Bjerck 2017).

The experimental building of traditional Koniag sea vessels, together with the ethnographic data on Koniag skin boat manufacture, demonstrates the very delicate care needed to handle the skins intended for covering boats/kayaks (Haakonson pers.

[9] Given the ecological importance of the White Sea as a major breeding ground for the western Arctic Harp seal population, adjacent land areas seem like a hot candidate for the maritime shift in Eurasian slate technologies. Unfortunately, the Kola Peninsula and White Sea coast are poorly surveyed and scarcely excavated. Efforts should be made to increase the archaeological visibility of this area in future research.

comm). This is supported by ethnographic and experimental work from elsewhere as well (Ames 2002, p. 33; Arima 1961; Johnstone 1972; Marstrander 1976, p. 20). Kodiak/Alaska Natives in historic times would avoid using male sealskins as they are more frequently perforated during fighting. Despite the fact that sealskin covers could be repaired, covering boats/kayaks in a double layer of skin was apparently not an option due to weight and drag issues. Skin coverings were removed each autumn, to be replaced on an annual basis, and six large harbour sealskins were necessary to cover one kayak (Haakonson pers. comm). Boat manufacture was subject to strict gender-based division of labor, as only females were thought to possess the knowledge and nimbleness of hand necessary to properly process skin coverings. All of this contributes to the idea that the limiting factor in maritime adaptations is skin boat production, in which the preparation and quality of sealskins are absolutely crucial. The particular suitability of slate knives in processing and skin preparation support their pivotal role in boat manufacture.[10]

It is seemingly paradoxical that pre-slate people in Arctic Norway also depended on seal resources and that they did well without slate tools. This could be explained by ESA seal exploitation being mainly directed at small scale hunting for dietary and limited technological needs (kayaks). In contrast, LSA seal exploitation may have been more a by-product of intensified and organized deep-sea fishing, requiring large quantities of seal products for more and larger boats (canoes/umiaks). This is not to undermine the dietary importance of seal during the LSA. Seals provide important fat, calorie and iron supplements to a diet otherwise dominated by lean white fish, of which an exclusive intake of cod may result in scurvy. Dietary analysis of the only mid-Holocene individual from northern Norway suggests a spectacular intake of high-trophic marine resources (Günther *et al.* 2018).

Yet, there is no reason why slate tools should not be used for hunting/processing of terrestrial resources. My claim is rather that the widespread use and maintenance of slate technologies is unlikely to occur among strongly terrestrial populations. This is due to the density-dependent nature of marine resource exploitation, which apparently only becomes cost-effective under elevated population densities that offset the higher start-up costs of intensified maritime economies. These factors are simultaneously conducive to counter the higher investment costs of slate technologies, and by implication, the slate industry itself should be density dependent. Although slate tools are more than sufficient in processing terrestrial products, they are clearly not conditional. This is well illustrated by the intense use of cryptocrystalline scrapers at the various inland sites in Arctic Norway where mass harvesting of ungulates was a primary

[10] Note that various skin and hide products are known ethnographically for making boat and kayak coverings (Chapelle and McPhee 2016; Heath 2004; Pedersen 1986); *e.g.*, interior boat technology of arctic Canada (Caribou Inuit and Chipeweyan) made kayaks covered in reindeer skin to navigate interior lakes and rivers, while Nahane and Cree used moose or deer hides (Birket-Smith 1929, pp. 172–173). However, such coverings seem to have been less durable, making sealskin preferable when accessible. This is indicated by ethnographic records noting that the ungulate hide-covered kayaks of Southern Alaska were mainly of a temporary character in order to transverse inland rivers on the way back to the coast where sealskin covered boats were employed (Birket-Smith 1929, p. 78). This plays into the picture of sealskin coverings having been the dominant technological solution to larger open-water vessels across the circumpolar area—documented ethnographically and archaeologically both sides of the Bering Strait (Chapelle and McPhee 2016; see also Chapelle 1951), Greenland (Grønnow 2017) and apparently in prehistoric northern Europe (see review in Van de Noort 2011, p. 149).

engagement throughout the Holocene (Hood 2012). That no slate knives are known from such sites is indicative of important differences in processing requirements of marine and terrestrial products. This pattern is repeated on both sides of the American Arctic with a limited distribution of slate tools into the interior.

Upscaling Phase: Slate as an Enabling Technology and Its Demographic Impact

The empirical results and discussion presented so far suggest that slate technology is particularly beneficial in terms of its potential for combining various technological efficiency variables, such as maintainability, reliability and standardization into super-efficiency. The profound implication is that the slate industry meets the criteria of "enabling technologies"; that is, a technology that radically alters the capabilities of its users. The crucial matter then is how the advantages of slate as an enabling technocomplex translate into increased adaptive success on the population level. The fact that the slate abundance index strongly corresponds to the palaeodemographic trend implies two competing hypotheses on the directionality of the underlying causation:

A. Adopting slate technology provides higher yields in marine resource exploitation that results in population growth.
B. Population growth (driven by some other factor) necessitated an intensification of marine resources in which slate technology was already an integral part.

It is currently not feasible to settle this chicken or the egg issue empirically. Regardless, I suggest that the causal relation between slate technology and demography is best described by the middle-range mechanism of "scale economy". Scale economy describes the efficiency benefits that occur in circumstances where the increased scale of production reduces the cost per unit output. The organization of slate tool production and maritime subsistence is particularly well suited to reap the benefits of scale economies. In order to achieve such benefits, the system must realize "increasing returns to scale" (IRS). That is, outputs must increase by more than the proportional change in all inputs (Britannica 2016). This is only possible through standardization of workflow, equipment and skills that reduce the costs of individual outputs (Britannica 2011). The total cost of a scale economy may be higher because of additional start-up costs, yet the average output cost is lowered when producing sufficient quantities.

The scale economy of slate industries is illustrated in Fig. 9. It demonstrates the relationship between the critical variables of (1) environmental productivity, (2) population size, (3) ideal free distribution and at what point population thresholds kick in that (4) make the slate industry economically viable and (5) enables a scale economy.

There is minimal literature on how economies of scale may be achieved in foraging societies and it is rarely treated as an explicit mechanism in human behavioural ecology or archaeology (*e.g.* Freeman 2016; Freeman and Anderies 2012; Hooper *et al.* 2015; Bettinger 2015). When discussed, the main focus has been directed at agricultural household and state economies (Smith 2004), often under the heading of "Chayanov's rule" of peasant production (Sahlins 1972, .p. 87; Smith 1979a, b; *cf.* Hammel 2005; Hirth 1996). However, it is a fundamental mechanism useful for connecting the economic, demographic and social properties of a population.

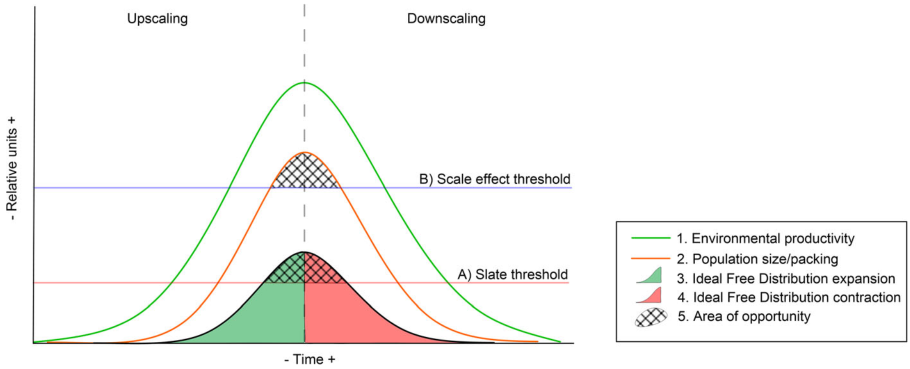


Fig 9 Conceptual model of the density-dependent character and temporal dynamics in the scale economy argument. The model homes in on one upscaling/downscaling cycle. Assuming that changes in environmental productivity produce corresponding dynamics in population size and packing (expansion/contraction of ideal free distribution patterns), there are density-dependent thresholds at which point **a** slate uptake becomes economically viable and **b** a scale economy is achieved. Produced in Grapher 12

Importantly, the point of a scale economy is not ultimately to reduce production costs, but by doing so, increase profits. The applicability to non-market, HG/pre-industrial economies is not straightforward however, as what should be the currency of profit in human ecology is contested. This is because purely rational economic considerations are not fully sufficient in mapping onto real decision-making processes. The application of profit maximization is arguably less appropriate in foraging societies (sensu "limited needs", "satisficing" and "constrained optimization") (reviewed in Smith 1987a; *cf*. Pearson 1957; Smith 1987b). However, such shortcomings have been dealt with as part of the debate over adaptive strategies focusing on optimization vs risk reduction (Foley 1985; Winterhalder 2001, p. 31). Within the deep-time context of human evolution, which is subjected to various selective pressures, reproductive fitness is the universal currency (Smith 1979a, b). I suggest subsistence technologies answer directly to these selection pressures and thus propose that *the slate technology contributed to increased reproductive fitness.*

The constituents of what makes the positive contribution to fitness come down to the social organization of the slate industry and its role within the maritime adaptive niche. Maritime slate technologies tentatively achieve "internal" economies of scale of the "technical" sort, in which the use of specialist equipment or processes boost productivity. I propose that the scaling occurs both in the production phase of slate tools through standardized, serial production, as well as through use in multi-component, replaceable part technologies. Most significantly though, the scaling results from the particular "enabling" properties of slate technologies. This is realized when acting as a catalyst for increased efficiency across various subsistence processes, not only does it solve existing problems better than other hunting and processing technologies but it also enables a more efficient acquisition of secondary products and, crucially, enables other enabling technologies to perform better—contributing to better boat manufacture.

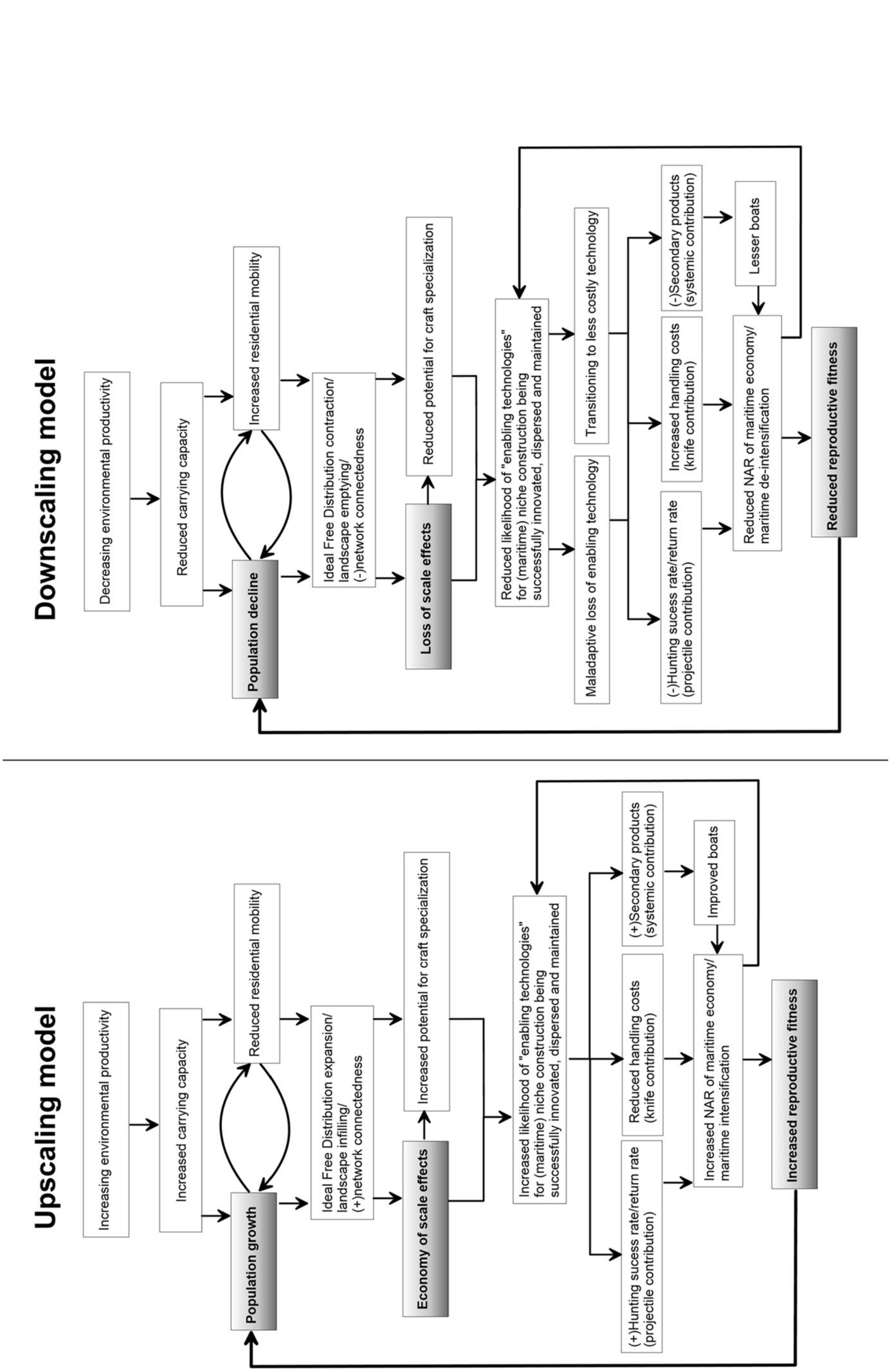
Specifically, the adaptive benefit stems from feedback loops between increasing population size and reduced handling costs of marine resources and tool production costs. Slate tools increase the return rate of aquatic resource exploitation, particularly through reducing the handling costs of mass-harvested fish resources but also that of skin preparation. Both are labor-intensive and time-consuming activities that act as technological constraints in maritime adaptations. Reducing the handling cost of fish can shift the resource ranking, resulting in a positive feedback loop where slate technology drives increased fishing which drives further reliance on slate tools over other lithic technologies, *etc*.

The prospects for establishing a scale economy are context specific, given the environmental setting and economic adaptation of the population in question. Yet, the mechanism is of general relevance. The bigger the game hunted, or the more complex the hunting procedure, the bigger the benefits of a scale economy. This is because the hunting efficiency of foragers depends non-linearly upon the size of hunting parties, as there are thresholds involved. Empirical studies have demonstrated that while per capita production stays constant with the inclusion of an additional hunter to small parties (< 3), per capita returns can be significantly greater in groups of four and five members (Hooper *et al*. 2015). As such, "the size of parties pursuing a given resource will reflect returns to scale in the production of that resource" (Hooper *et al.* 2015, p. 5). Thus, the structure, abundance, distribution, *etc*. of the preferred prey predict demographic and economic properties of human foraging populations. The implication is that group formation for ephemeral exploitation of unpredictable resources is very different from that of skill-intensive exploitation of packed and predictable resources (Demps and Glover Klemetti 2014)—the latter being characteristic of most coastal adapted groups. In terms of maritime adaptations, this relation should be even more pronounced, whale hunting being the classic example (Sheehan 1985). Although intensified fish exploitation is a more common economic pursuit, it may equally benefit from a scale economy. Standardized slate tool production increases productivity and reduces costs per unit in intensified fish exploitation, thereby turning it into an economy of scale.

These complex relations are summarized in Fig. 10. It presents a system chart of the up- and downscaling causal pathways potentially mediating environmental and ecological variability into human demographic effects through socio-technical responses. Initially, environmental conditions drive the basic demographic potential of the population. In the upscaling phase, the increased carrying capacity of the environment results in population growth, which itself enters a reinforcing loop with sedentism. Increased sedentism, packing and landscape infilling enables scalar effects in the slate industry, which is mediated through enabling components of specific slate technologies that increase the net acquisition rate (NAR).[11] Increased NAR feeds back into a loop that reinforces investment into the enabling technologies driving the process. Eventually, increased NAR results in increased reproductive fitness which drives population growth—thus retiring the entire upscaling process.

An important theoretical assumption of the model is that the slate industry is density dependent, in a twofold sense: (a) the technological benefits of slates are particularly pronounced when *the resources to be procured occur in high density* and (b) when there is a *high density of the human population* supporting the slate technology. Note that such density dependence does not entail a principle obstacle to maintaining any slate technology among low-density populations. Yet, it does not seem economically *viable* when the

[11] NAR (Rn) is formally defined as $(Rn = [Ea - Ee]/Ta)^2$ (Smith 1979b, p. 60). That is, energy acquired (Ea) − energy expended (Ee)/foraging time (Ta) + processing time. Note that "processing time" was not included in Smith's original publication but implicitly assumed in the variable "time spent foraging or acquiring energy in any fashion (Ta)".


Downscaling model
Decreasing environmental productivity
Reduced carrying capacity
Population decline
Increased residential mobility
Ideal Free Distribution contraction/
landscape emptying/
(-)network connectedness
Loss of scale effects
Reduced potential for craft specialization
Reduced likelihood of "enabling technologies"
for (maritime) niche construction being
successfully innovated, dispersed and maintained
Maladaptive loss of enabling technology
Transitioning to less costly technology
(-)Hunting sucess rate/return rate
(projectile contribution)
Increased handling costs
(knife contribution)
(-)Secondary products
(systemic contribution)
Lesser boats
Reduced NAR of maritime economy/
maritime de-intensification
Reduced reproductive fitness
Upscaling model
Increasing environmental productivity
Increased carrying capacity
Population growth
Reduced residential mobility
Ideal Free Distribution expansion/
landscape infilling/
(+)network connectedness
Economy of scale effects
Increased potential for craft specialization
Increased likelihood of "enabling technologies"
for (maritime) niche construction being
successfully innovated, dispersed and maintained
(+)Hunting sucess rate/return rate
(projectile contribution)
Reduced handling costs
(knife contribution)
(+)Secondary products
(systemic contribution)
Improved boats
Increased NAR of maritime economy/
maritime intensification
Increased reproductive fitness

◀ **Fig 10** System flowchart of causal linkages summarizing the argument presented in this paper. It demonstrates the micro/macro causal pathways potentially mediating environmental and ecological variability into human demographic effects through socio-technical responses. Note that the up- and downscaling models are slightly different, capturing the various mechanisms that are activated during the various phases of the maritime population peak period. Also note that there is more uncertainty connected to how the slate industry is causally related to the other system components in the downscaling phase, as less data is available for that period. Produced in Grapher 12

population density falls below a certain threshold, as technological investment costs exceed potential returns. Demographic thresholds are known to affect the potential for successful knowledge transmission and maintenance of complex technologies, which are density-dependent processes in themselves (Ugan *et al.* 2003; Winterhalder *et al.* 1988). Larger/denser populations and network expansion make it easier to establish labour division and craft specialization. It is expected that expert crafting is restricted to a few, specialized individuals (Ames 2002, p. 32). This is indicated in the slate industry by tools being more elaborately made during the population peak (early slate period) compared with the late slate phase, such as the daggers and leaf-shaped points. The density-dependent character of the slate industry is furthermore indicated by the covariation in quantitative and qualitative aspects of the slate industry and population characteristics (see Results).

Downscaling Phase: Why the Reduction in the Use of Slate?

Finally, there is the issue of why the long and prosperous technological tradition of the Arctic Norwegian slate industry was drastically reduced alongside the population decline and eventually abandoned. The downscale phase mirrors the negative impact of the reduced carrying capacity of the variables in the upscaling phase model. Yet, there are particular elements to the downscaling which is discussed below.

There exists a large set of opposing hypotheses for explaining cases where technology, demography and ecology change in synchrony. A much-debated proposition during the last decades is whether the cultural transmission is impeded by declining populations, undercutting the potential for maintaining complex technologies (Collard *et al.* 2016; Henrich 2004; Vaesen *et al.* 2016). Concerning the downscaling of efficient technologies, explanations have focused on either adaptive transitions into other forms of technologies (Bettinger *et al.* 2006) or maladaptive loss (Henrich 2004). Empirically, testable predictions of these models are presented in Table 4.

Applying this to the Arctic Norwegian case is useful for dissecting the causality of the downscaling phase. The evidence from Norway suggests significant changes to population density that is also related to technological changes. On the one hand, the duration of change within the slate industry is rapid (in phasing out the early production sequence and associated tool types). On the other hand, it is also slow (in general trends toward smaller,

Table 4 The drivers and responses of technological change in relation to cultural transmission. Adapted from (Codding and Jones 2010, p. 83)

	Maladaptive loss	Adaptive transitioning
Duration of technological change	Prolonged deterioration of knowledge	Rapid change in technology relative to a rapid environmental shift
Character of technological change	Return to simpler technologies	Incorporation of new technologies

more standardized tools and fewer types). Furthermore, the character of technological change seems to be a combination of both maladaptive loss (of important slate tools following the shift away from the early production sequence) and adaptive transitioning (to metal products).

There is seemingly a paradox that the population was smaller when slate was first adopted than after the major population decline. I would argue that the reason why it was possible to maintain a reduced form of the slate technology after the population decline is due to founder effects: benefitting from prior investments and technological know-how developed during more suitable ecological conditions pre-decline. As the population fell below the critical threshold necessary to gain increasing returns to scale (IRS), the economic system would instead pass through constant returns before eventually settling into a negative spiral of reduced returns to scale. The implication is that upholding an economy of scale and skill in slate technology became untenable within a smaller/less dense population. This is because (1) a reduced population potentially impedes the necessary knowledge transmission for upholding "skill-led" technologies and (2) because the division of labour used in "production-chain efficiencies" could not be sustained in smaller groups.

Although slate technology continues to be in use for approx. 3000 years after the 5500 cal BP population decline, it lost much of its former economic importance, and significant changes occurred in tool concepts and artefact types. The general climate cooling post-HTM resulted in reduced environmental productivity and has been proposed as the large-scale ecological mechanism responsible for the 5500 cal BP demographic downturn (Jørgensen *et al.* 2020). Based on the causal linkages discussed in Fig. 10, the demographic decline seems a likely catalyst for technological downscaling.

One possibility is that the correlated downscaling in demographic and technological proxies results from the adaptive niche constituting a "growth system" (sensu Culbert 1988, p. 77). For instance, growth-dependent hunting practices of density-dependent species with slow reproduction rates and high parental investment in offspring would only be sustainable given continuously increasing environmental productivity. This would be the case for high-ranking/large-bodied marine and terrestrial mammals. They would be susceptible to overexploitation as they were key nutritional and technological resources simultaneously. Comparatively, fish are generally re-selected, reproducing rapidly through large offspring cohorts. Subsistence strategies fueled by increasing returns to scale run the risk of ecological overshooting when peak productivity plateaued at ca 5800 cal BP and went into decline (Jørgensen 2018; Jørgensen *et al.* 2020). Exploiting critical resources in sustainable ways is generally associated with real risks. This becomes all the more pressing given the role of boats as the constraining technology in the adaptive niche of maritime environments. The requirements put on skin coverings by boat manufacturing may have had negative feedbacks on seal populations and consequently driven down the availability of suitable skins. Large individuals would be preferable to reduce the number of seams. However, specifically targeting large (mostly female) individuals run the risk of quickly destabilizing the entire seal population. The ongoing deforestation at the time of the 5500 cal BP human population decline, limiting the availability of suitable timber, may have impacted boat technology in favour of smaller and less costly sea vessels with other performance characteristics. This finds support in the hiatus in rock art boat depictions. Tentatively, these factors could conjoin and result in reduced adaptive fitness.

The character and timing of the adaptive adjustments during the downscaling phase might suggest a Malthusian trap in which the population emphasized a niche of decreasing adaptive potential, analogous to “aggregation traps” in which organisms are attracted to patches of environment that are poor adaptive choices (Phillips *et al*. 2018, p. 227; see also, Hill *et al*. 2010, p. 48). This could be instigated by reduced carrying capacities of the post-HTM environment, resulting in reduced human population and technological stress. It might also require economic intensification *sensu stricto*, necessitating increased work input to maintain a system providing rapidly diminishing returns and a contracting IFD.

Also, predictable risk mitigation responses to population decline are economic shifts, increased mobility and technological downscaling (Minc and Smith 1989). Following cultural transmission theory, a population experiencing decline and IFD contraction should prioritize less skill-intensive implements. This is because skill-intensive technologies are only sustainable under certain, density-dependent conditions, provided by a sufficient market of skilled learners and users, efficient dispersal mechanisms, sufficient adoption rates, *etc*. Such markets are best provided through a high-density local population or an extended regional network (Derex *et al*. 2018; although *cf.* Read 2008, p. 620). The various technological results presented here are in line with this prediction. There is a general reduction in the use of slate tools, reduced number of tool types and a priority of easily standardized tools that arguably are more “democratic” and less network dependent in their production sequence. The late slate phase technology seems to be more of a “socially distributed” character. Comparatively, the demographic conditions of the early slate phase, consisting of peaking IFD expansion, population packing and increased network interconnectedness, facilitated stronger craft specialization and a more skill-led technology.

Importantly, the impact of population decline on cultural transmission of the slate industry is not uniform. Rather, it is particular to the projectile point and knife technology. The earlier phasing out of slate knives in favour of a slate record almost entirely consisting of small, highly standardized projectile points of the fluted Sunderøy type might seem counterintuitive as projectiles can be produced from lithic materials of lower extraction, transport and processing costs. Slate knives are less flexible in this regard. This result violates the expectation that if priorities had to be made within the slate complex, one would go with making knives over projectiles, given the particular suitability of slate as enabling technology in boat manufacture. The introduction of functional equivalents of slate knives, such as copper or iron cutting tools, provides a plausible explanation for the earlier disappearance of slat knives (see Results and Fig. 6).

Conclusion

Based on a wide review and extensive empirical investigations, this paper demonstrates remarkable concomitant changes across multiple parameters in the human ecodynamics system of mid-Holocene Arctic Norway. This consisted of a strong correspondence between population size, maritime intensification and the use of slate technologies. It is suggested that the causal mechanism responsible for this correspondence is that the slate industry facilitated a heightened adaptive success through the intensification of maritime resources, particularly that of deep-sea fishing. This was enabled by scalar properties of the slate industry when surpassing critical thresholds in ideal free distribution, increased sedentism and coastal population packing. The particular adaptive benefit of the slate industry is attributed to the multiple contributions to increasing the net acquisition rate (NAR) in the maritime economy, both by increasing the return rate as well as reducing handling costs of hunting and processing of marine resources (fish and marine mammals), thereby offsetting the high- and density-dependent start-up costs. Crucially, the adaptive benefit relies on a reinforcing loop between increased NAR and the increased technological capabilities for dietary and essential non-dietary products. The slate technology facilitated an intensification of deep-water fish resources and instigated a secondary products revolution of essential, non-dietary marine resources—driven by positive impacts on boat manufacture.

Technological results suggest superior qualities for standardization make slate technologies particularly well suited to establishing scale economies in maritime resource exploitation. Satisfying more or less all categories of "efficient" technologies, it is concluded that slate is an "enabling technology" that greatly advances the adaptive capabilities of the population, when certain conditions are met, such as elevated population packing, increased sedentism and the economic targeting of stable and densely packed resources. These conditions are typically met in the context of high latitude, maritime populations and proposed as the very reason why slate technologies display a corresponding distribution.

Answering to the overall ambition, the paper accounted for the different processes that drive the up- and downscaling phases of the correlated changes in demography, environment, economic intensification and slate technology, thereby contributing to our understanding of technological evolution and complexity among prehistoric hunter-gatherers. This was done by presenting a generalized model of the causal pathways in which the slate industry interacted with environmental and demographic variables in maritime adaptive niches. The model was informed and tested with the empirical record from Arctic Norway.

Contrary to the ease with which some accept correlated technological and environmental changes as evidence of adaptive transitioning (*e.g.* Codding and Jones 2010), I am more hesitant. The findings of the current paper suggest there is no fundamental opposition between the empirical predictions of either adaptive transitioning to less costly technologies or maladaptive loss of enabling technologies. Rather, the interplay between technological and socio-ecological change may only be comprehensible through middle-range studies that account for historically contingent factors in particular cases. Ultimately, such studies may be aggregated into general mechanisms driving human adaptive strategies.

The fact that ecological, demographic and technological changes apparently converge into specific system states that the population alternates between, suggests generalized tipping points in the constellation of socio-ecological factors. This should not be taken as an endorsement of naïve stable equilibrium assumptions in human ecodynamics. Disequilibrium, through, *e.g.* maladaptation and population collapse, is becoming increasingly recognized in the literature as important historical events that shape human biological and cultural evolution (Gurven and Davison 2019; Riede *et al.* 2018). Yet, the density-dependent character of the circumpolar slate industries is indicative of important mechanisms influencing the successful outcome of maritime adaptive strategies. Here I have highlighted "scalar effects" as a potential middle-range mechanism for explaining the density-dependent thresholds that determine the timing and character of up- and downscaling within the slate industry of a circumpolar, maritime population. This was illustrated by a case study of Holocene Arctic Norway.

Although there are many unanswered questions to be addressed by future research, some areas are in particular need of attention in order to advance our knowledge of maritime adaptive strategies and the role of slate technologies:

- Perform large-scale use-wear analysis of slate implements within and between slate industries in order to determine the function and potential variation.
- Construct reliable foraging time and cost estimates of marine resource exploitation in order to test the assumed priority and higher NAR of maritime adaptations.
- Improve our understanding of the socio-ecological conditions driving or disparaging the uptake and maintenance of slate technologies. This can be done by filling in the gaps of Arctic coastal stretches that are not well represented at this point, such as the Siberian north coast and by engaging in detailed comparative studies.
- Produce an extensive body of experimental studies of slate technologies that (a) cover the entire production sequence, (b) do comparative work on fully percussive vs chocolate plate production techniques and (c) establish the performance characteristics of specific tool types.
- Comparative studies of slate technologies alongside functional equivalents, such as bone and metal implements, are necessary to determine the technological affordance, development and cost/benefit considerations that go into the priority of slate over other alternatives.

Pursuing these issues will help us overcome the dominant culture-historical treatment of circumpolar slate industries and help reinvigorate the study of an immensely interesting characteristic of the circumpolar past. If addressed systematically, we can move toward a stronger analytical framework able to integrate slate subsistence technologies with the overall socio-ecological system. Ultimately, this framework should account for the convergent evolution among the separate, slate using groups in the circumpolar north, by way of explaining why the individual slate industries were adopted at the time and in the places that they were. My hope is that the current paper has convinced the reader that circumpolar slate industries hold great promise as case studies for identifying and dissecting the general processes that produce interlinking between demographic and ecological parameters, and the technological capabilities of human populations.

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Compliance with Ethical Standards

Conflict of Interest The author declares that they have no conflict of interest.

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Personal communication

Haakonson, Sven. Personal communication. December 2018. Burke Museum, Seattle, Washington, USA. Haakonson was reconstructing a traditional Koniag Alutiiq kayak with the help of Alaska Native expert boat builders. The information referenced in the text was shared during a visit to a boat building session during a research stay at UW, Seattle.