Journal of Archaeological Method and Theory
https://doi.org/10.1007/s10816-020-09458-7

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

Erlend Kirkeng Jørgensen[1]

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.

Electronic supplementary material The online version of this article (https://doi.org/10.1007/s10816-020-09458-7) contains supplementary material, which is available to authorized users.

✉ Erlend Kirkeng Jørgensen
erlend.k.jorgensen@uit.no

[1] Department of Archaeology, History, Religious Studies and Theology, UiT - The Arctic University of Norway, Langnes, Post box 6050, 9037 Tromsø, Norway

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.

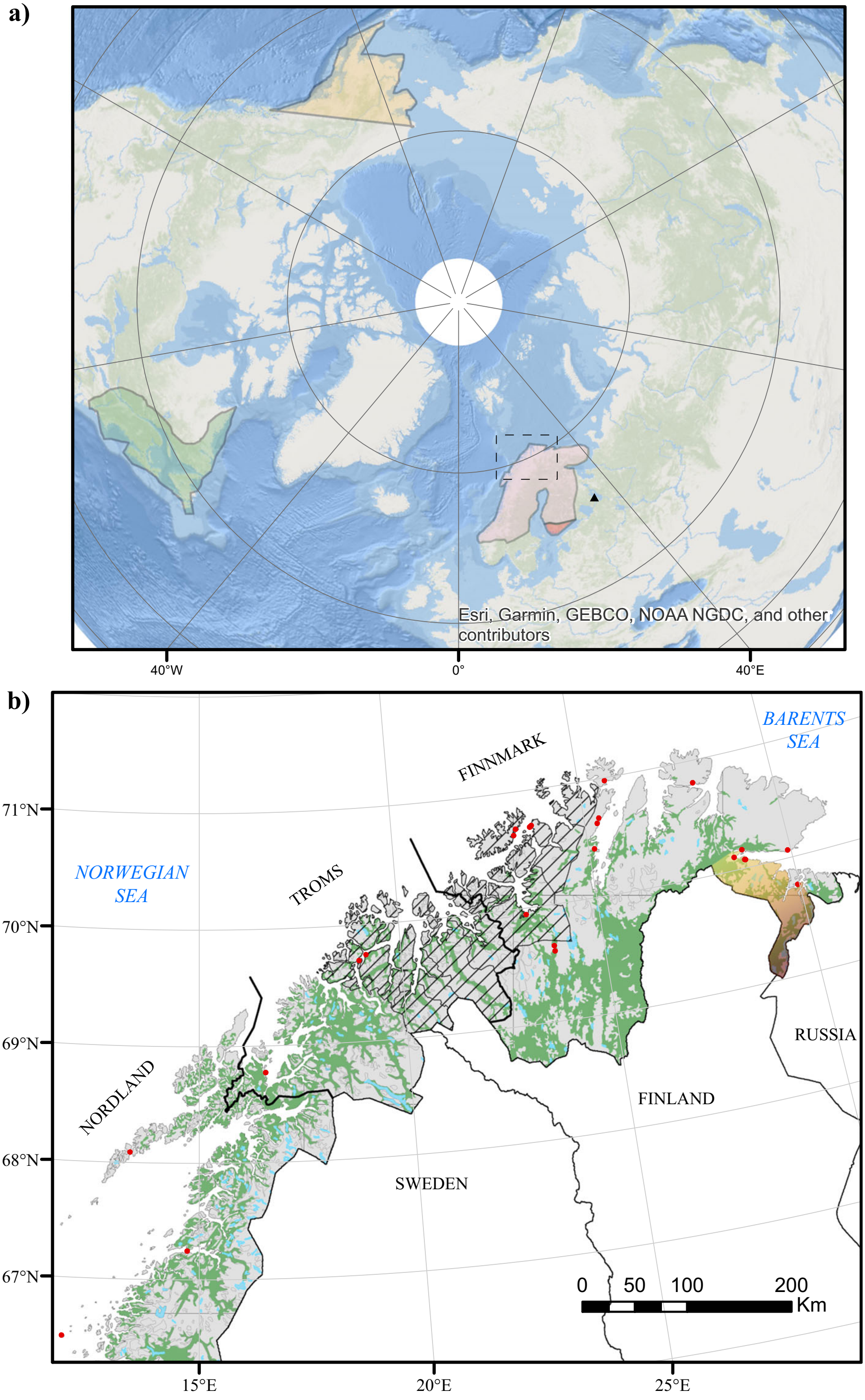
Background

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.

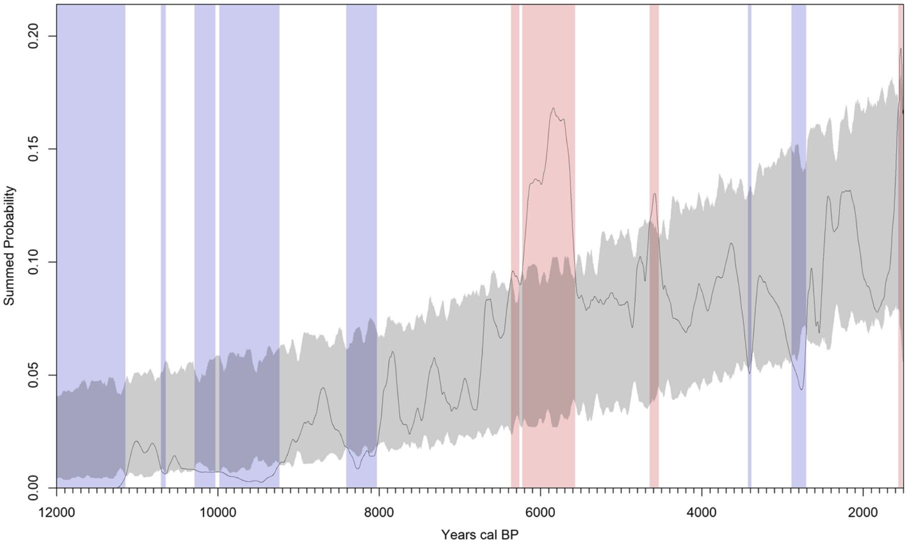


Fig 3 Palaeodemographic model of the population trajectory on the basis of ($N = 735$) dates from coastal sites in NW Arctic Norway (hatched area marked in Fig. 1). Red bars correspond to positive deviations from the expected exponential growth interval (marked in grey). Blue bars correspond to negative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

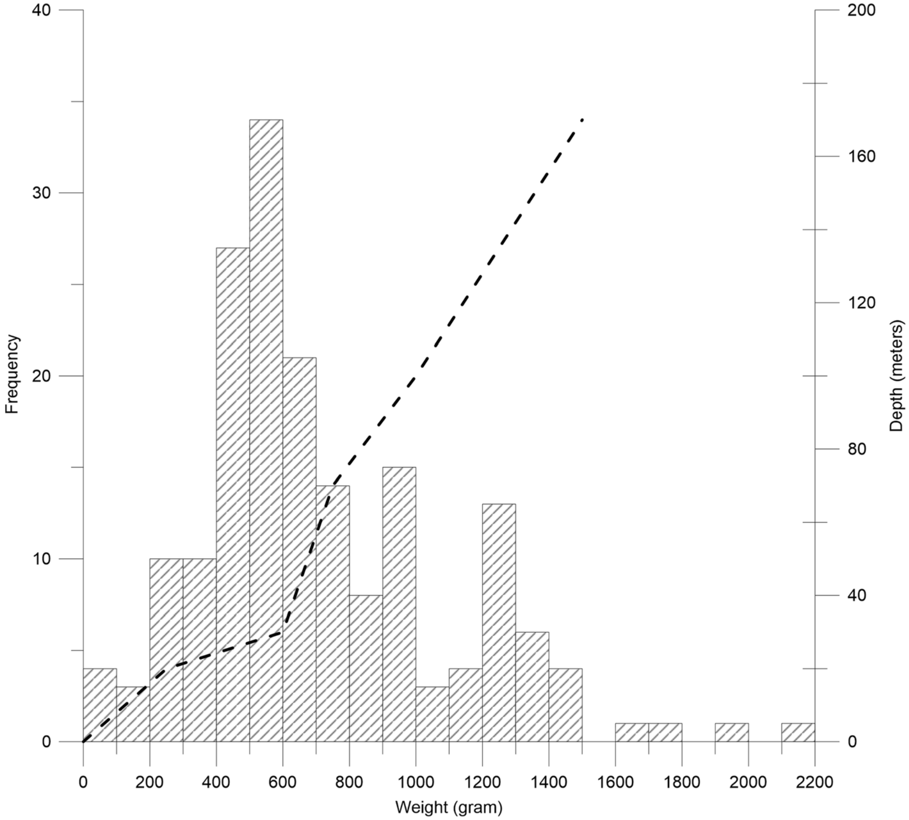


Fig 4 Weight distribution of $N = 180$ sinkers found alongside mid-Holocene slate assemblages. 100-g bins. Plotted against ideal weight:depth ratio for line fishing. See also data in Andreassen (1985, p. 217), Simonsen (1996, p. 185) and Utne (1973). Produced in Grapher 12

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

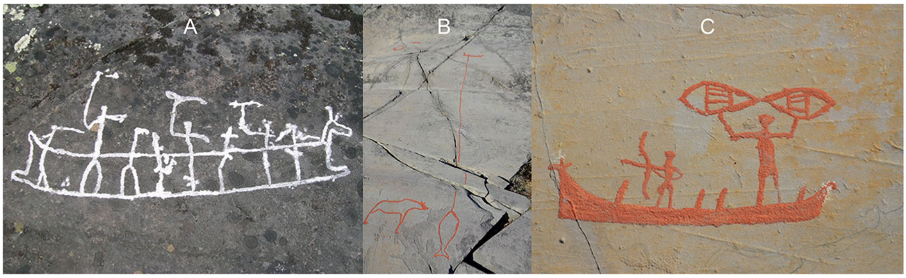


Fig 5 Rock art depictions of pre-decline boats and marine hunting activities. Boats are regularly displaying moose figures at the prow and with multiple human figures. **a** Boat carrying approximately seven human figures, some of which are holding objects on unknown nature. **b** Depiction of deep-sea 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

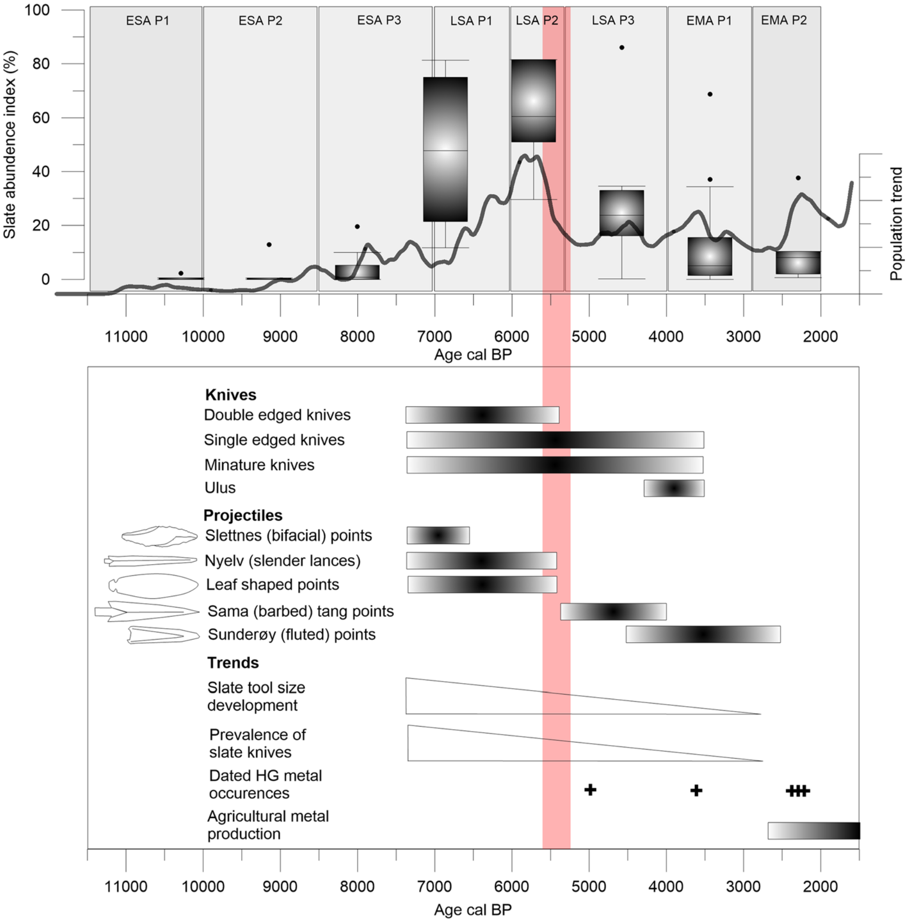


Fig 6 Upper section—the slate abundance index (SAI) mapping the relative proportion of slate, based on the frequency of raw materials in selected site assemblages plotted against the coastal population model of NW Arctic Norway. The SAI is presented as a box and whisker plot, with outliers given as dots. 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

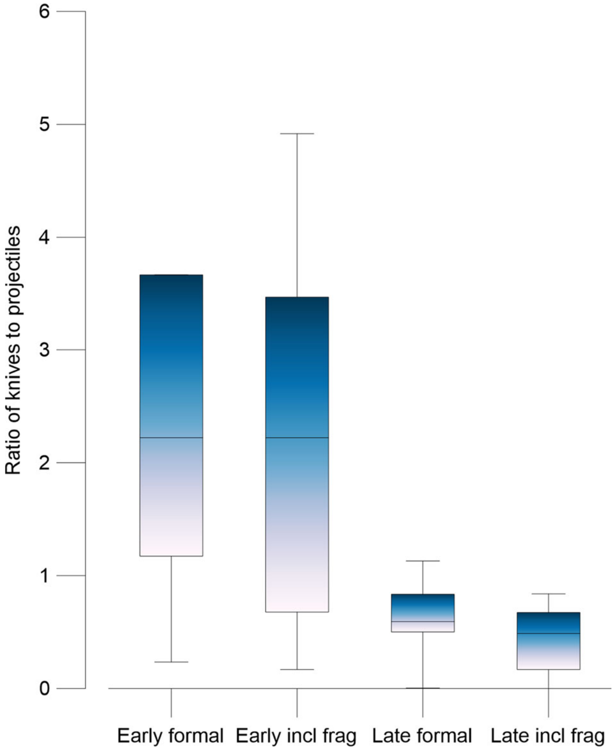


Fig 8 Box and whisker plot of slate knives-to-projectiles ratio based on 17 assemblages, classified as early and late industries. Plotted using the interquartile range factor. Produced in Grapher 12

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.

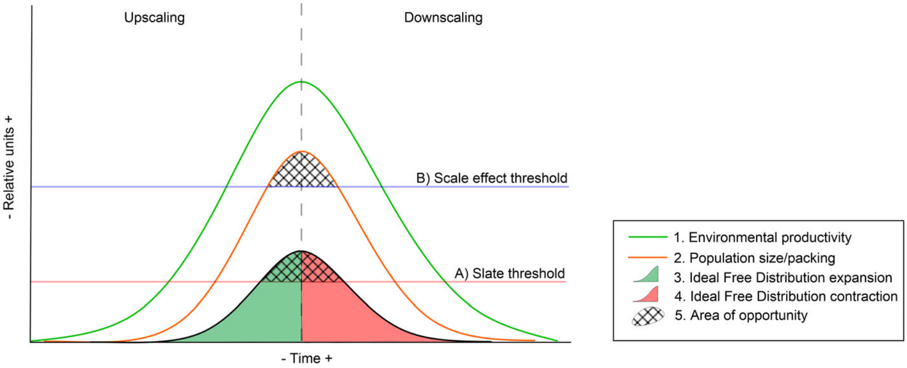


Fig 9 Conceptual model of the density-dependent character and temporal dynamics in the scale economy argument. The model homes in on one upscaling/downscaling cycle. Assuming that changes in environmental productivity produce corresponding dynamics in population size and packing (expansion/contraction 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*.

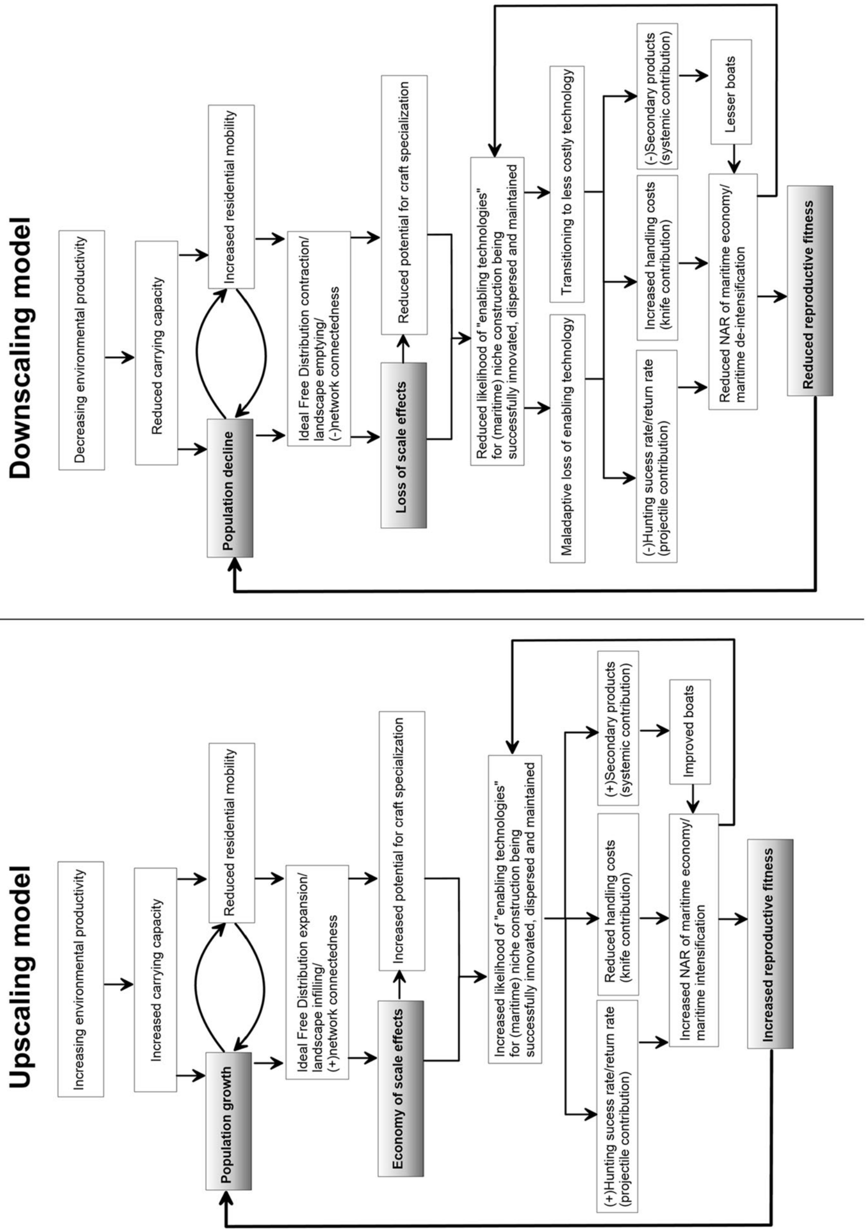
The prospects for establishing a scale economy are context specific, given the environmental setting and economic adaptation of the population in question. Yet, the mechanism is of general relevance. The bigger the game hunted, or the more complex the hunting procedure, the bigger the benefits of a scale 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)".


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
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

◀ **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.

Acknowledgements My sincere gratitude to Bryan Hood for extensive comments and lengthy discussions on topics related to this work. I am also grateful that Ben Fitzhugh, Enrico Crema, Felix Riede, Charlotte Damm and members of the "Stone Age Demographics" research group have provided constructive responses at various stages. I thank the Arctic University Museum for hosting me and providing access to materials. In particular, I would like to thank Tanja Hansen and Marianne Skandfer at the museum for their hospitality and generosity in enabling my empirical studies. I am grateful for the most useful feedback provided by a number of anonymous reviewers that helped improve this paper.

Funding Information Open Access funding provided by UiT The Arctic University of Norway. This work was supported by the "Stone Age Demographics" project funded by the Research Council of Norway (grant number: 261760) and through a doctoral fellowship funded by UiT - The Arctic University of Norway.

Compliance with Ethical Standards

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

References

Ahola, M. (2017). The material culture of Finnish Stone Age hunter-gatherer burials. *Fornvännen, 112*, 201–215.

Ames, C. (2009). *From chipped to ground: The spatio-temporal systematics of 9,000 years of archaeological change in southwest British Columbia (Master)*. Montreal: McGill University.

Ames, K. M. (2002). Going by boat. In B. Fitzhugh & J. Habu (Eds.), Beyond foraging and collecting: Evolutionary change in hunter-gatherer settlement systems (pp. 19–52). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4615-0543-3_2

Andreassen, R. L. (1985). *Yngre steinalder på Sørøy: økonomi og samfunn 4000-1000 f.Kr*. Tromsø.

Arima, E. (1961). How the umiak was built at Ivugivik. *Arctic Circular*, *XIII*(4), 58–62.

Arntzen, J. E. (2015). *Sandvika in northern Norway: The northernmost 'bronze age' settlement in Scandinavia* (pp. 3–34). *XXXII*: *Fennoscandia Archaeologica*.

Arntzen, J. E. (2013). The empirical basis for research on farming settlements in northern Norway 1200 BC–0. In D. L. Mahler (Ed.), *The Border of Farming Shetland and Scandinavia - Neolithic and Bronze Age Farming* (pp. 182–197). Copenhagen: The National Museum of Denmark.

Auset, H. (2007). *Fra brudd til kast: om framstilling av skifer pilespisser i yngre steinalder på Bøleseter og Bølestrand i Flatanger, Nord-Trøndelag (Master thesis)*. Trondheim, Norway: NTNU.

Äyräpää, A. (1950). Skifferspetsarna i östra Fenno-Skandien. *Finskt museum, 57*, 9–43.

Bailey, G. (2015). The evolution of the Red Sea as a human habitat during the Quaternary Period. In N. M. A. Rasul & I. C. F. Stewart (Eds.), *The Red Sea: The formation, morphology, oceanography and environment of a young ocean basin* (pp. 599–614). Berlin, Heidelberg: Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-45201-1_34.

Bakka, E. (1976). *Arktisk og nordisk i bronsealderen i Nordskandinavia*. Trondheim, Norway: NTNU Vitenskapsmuseet.

Balbo, A. L. (2015). Storage: Introduction to the special issue. *Environmental Archaeology, 20*(4), 305–313. https://doi.org/10.1179/1749631415Y.0000000021.

Baudou, E. (1992). *Norrlands forntid: ett historiskt perspektiv*. Skytteanska samf.

Bergsvik, K. A., & Hufthammer, A. K. (2009). Stability and change among marine hunter-fishers in Western Norway 7000- 4500 cal bc. Results from the Excavations of two Rockshelters in Hardanger. In Chronology and evolution within the Mesolithic in North-West Europe, *Chapter: 22, Publisher: Cambridge Scholars Publishing, Editors: Philippe Crombé, Mark Van Strydonck, Joris Sergant, Mathieu Boudin, Machteld Bats* (pp. 425–449).

Bergsvik, K. A. (2004). En etnisk grense ved Stad i steinalderen. *Primitive tider, 7*, 7–27.

Bettinger, R. L. (2015). *Orderly anarchy: Sociopolitical evolution in Aboriginal California*. University of California Press.

Bettinger, R. L., & Grote, M. N. (2016). Marginal value theorem, patch choice, and human foraging response in varying environments. *Journal of Anthropological Archaeology, 42*, 79–87. https://doi.org/10.1016/j.jaa.2016.03.002.

Bettinger, R. L., Winterhalder, B., & McElreath, R. (2006). A simple model of technological intensification. *Journal of Archaeological Science, 33*(4), 538–545. https://doi.org/10.1016/j.jas.2005.09.009.

Bevan, A., & Crema, E. R. (2018). *rcarbon v1.2.0: Methods for calibrating and analysing radiocarbon dates.* https://CRAN.R-project.org/package=rcarbon

Binford, L. R. (2001). *Constructing frames of reference: An analytical method for archaeological theory building using ethnographic and environmental data sets*. Berkeley: University of California Press.

Binford, Lewis R. (1980). Willow smoke and dogs' tails: Hunter-gatherer settlement systems and archaeological site formation. *American Antiquity*, *45*(1), 4–20. https://doi.org/10.2307/279653

Binford, L. R. (1990). Mobility, Housing, and Environment: A Comparative Study. *Journal of Anthropological Research, 46*(2), 119–152.

Birket-Smith, K. (1929). *The Caribou Eskimos: material and social life and their cultural position*. Copenhagen: Gyldendalske boghandel.

Bjerck, H. B. (2017). Settlements and Seafaring: Reflections on the integration of boats and settlements among marine foragers in Early Mesolithic Norway and the Yámana of Tierra del Fuego. *The Journal of Island and Coastal Archaeology, 12*(2), 276–299. https://doi.org/10.1080/15564894.2016.1190425.

Bjerck, H. B. (2008). *Ormen Lange Nyhamna: NTNU Vitenskapsmuseets arkeologiske undersøkelser - Nasjonalbiblioteket*. Trondheim, Norway: NTNU Vitenskapsmuseet.

Blankholm, H. P., Lidén, K., Kovačević, N., & Angerbjörn, K. (2020). Dangerous food. *Climate change induced elevated heavy metal levels in Younger Stone Age seafood in northern Norway. Quaternary International.* https://doi.org/10.1016/j.quaint.2020.01.019.

Bleed, P. (1986). The optimal design of hunting weapons: Maintainability or reliability. *American Antiquity, 51*(4), 737–747. https://doi.org/10.2307/280862.

Bleed, P. (1991). Operations research and archaeology. *American Antiquity, 56*(1), 19–35. https://doi.org/10.2307/280969.

Bocquet-Appel, J.-P. (2011). When the world's population took off: The springboard of the Neolithic demographic transition. *Science, 333*(6042), 560–561. https://doi.org/10.1126/science.1208880.

Boone, J. L. (2002). Subsistence strategies and early human population history: An evolutionary ecological perspective. *World Archaeology, 34*(1), 6–25. https://doi.org/10.1080/00438240220134232

Bousman, C. B. (1993). Hunter-gatherer adaptations, economic risk and tool design. *Lithic Technology, 18*(1–2), 59–86. https://doi.org/10.1080/01977261.1993.11720897.

Britannica. (2011). Economy of scale. In *Encyclopædia Britannica*. Encyclopædia Britannica, inc. https://www.britannica.com/topic/economy-of-scale. Accessed 13 December 2019

Britannica. (2016). Returns to scale. In *Encyclopædia Britannica*. Encyclopædia Britannica, inc. https://www.britannica.com/topic/returns-to-scale.

Broadbent, N. (1979). *Coastal resources and settlement stability: A critical study of a Mesolithic site complex in northern Sweden*. Uppsala, Sweden: Inst. för Arkeologi, särskilt nordeuropeisk.

Brøgger, A. W. (1909). *Den arktiske stenalder i Norge*. Dybwad: I kommission hos J.

Chapelle, H. A. (1951). Arctic Skin Boats. In (V. Stefansson, Ed.) *Encyclopedia Arctica 9: Transportation and Communications (unpublished reference work (1947-51)). Available at: https://collections.dartmouth.edu/arctica-beta/html/EA09-04.html*. https://collections.dartmouth.edu/arctica-beta/html/EA09-04.html. Accessed 19 December 2019

Chapelle, H. I., & McPhee, J. (2016). *Bark canoes and skin boats of North America* (Reprint ed.) Anboco.

Clark, D. W. (1979). *Ocean Bay: An Early North Pacific Maritime Culture*. Ottawa: National Museum of Canada.

Clark, D. W. (1980). Relationships of North Pacific and American Arctic centres of slate grinding. *Canadian Journal of Archaeology / Journal Canadien d'Archéologie, 4*, 27–38.

Clark, D. W. (1982). An example of technological change in prehistory: The origin of a regional ground slate industry in south-central Coastal Alaska. *Arctic Anthropology, 19*(1), 103–125.

Codding, B., & Jones, T. (2010). Levels of explanation in behavioral ecology. *California Archaeology, 2*(1), 77–92. https://doi.org/10.1179/cal.2010.2.1.77.

Collard, M., Vaesen, K., Cosgrove, R., & Roebroeks, W. (2016). The empirical case against the 'demographic turn' in Palaeolithic archaeology. *Phil. Trans. R. Soc. B*, *371*(1698), 20150242. https://doi.org/10.1098/rstb.2015.0242.

Crowell, A. (1994). Koniag Eskimo poisoned-dart whaling. In W. W. Fitzhugh (Ed.), *Anthropology of the North Pacific Rim* (pp. 217–242). Washington, DC: Smithsonian Institution Press.

Culbert, T. P. (1988). The collapse of Classic Maya civilization. In N. Yoffee & G. L. Cowgill (Eds.), *The collapse of ancient states and civilizations* (pp. 69–101). Tuscon: University of Arizona Press.

Damm, C. B., Skandfer, M., Jørgensen, E. K., Sjögren, P., Vollan, K. W. B., & Jordan, P. D. (2019). Investigating long-term human ecodynamics in the European Arctic: Towards an integrated multi-scalar analysis of early and mid Holocene cultural, environmental and palaeodemographic sequences in Finnmark County, Northern Norway. *Quaternary International*. https://doi.org/10.1016/j.quaint.2019.02.032

Damm, Charlotte B. (2012). Interaction: When people meet. In Gulløv, H.C. (Ed) Northern Worlds – landscapes, interactions and dynamics. PNM Publications from the National Museum. Studies in Archaeology and history Vol 22. Copenhagen, University Press of Southern Denmark. 227-239.

Darmark, K. (2012). Surface pressure flaking in Eurasia: Mapping the innovation, diffusion and evolution of a technological element in the production of projectile points. In P. M. Desrosiers (Ed.), *The emergence of pressure blade making: From origin to modern experimentation* (pp. 261–283). Boston, MA: Springer US. https://doi.org/10.1007/978-1-4614-2003-3_10.

Demps, K., & Glover Klemetti, S. M. (2014). Ephemeral work group formation of Jenu Kuruba honey collectors and late 19th Century Colorado silver prospectors. *Behaviour, 151*(10), 1413–1432. https://doi.org/10.1163/1568539X-00003192.

Derex, M., Perreault, C., & Boyd, R. (2018). Divide and conquer: intermediate levels of population fragmentation maximize cultural accumulation. *Phil. Trans. R. Soc. B*, *373*(1743), 20170062. https://doi.org/10.1098/rstb.2017.0062.

Edinborough, K., Porčić, M., Martindale, A., Brown, T. J., Supernant, K., & Ames, K. M. (2017). Radiocarbon test for demographic events in written and oral history. *Proceedings of the National Academy of Sciences, 114*(47), 12436–12441. https://doi.org/10.1073/pnas.1713012114.

Engelstad, E. (1983). *The Iversfjord locality: a study of behavioral patterning during the late stone age of Finnmark, North Norway*. Tromsø: Tromsø museum.

Engelstad, E. (1984). Diversity in arctic maritime adaptations: An example from the Late Stone Age of arctic Norway. *Acta Borealia, 1*(2), 3–24. https://doi.org/10.1080/08003838408580310.

Engelstad, E. (1985). The Late Stone Age of Arctic Norway: A review. *Arctic Anthropology, 22*(1), 79–96.

Engelstad, E. (1988). Pit houses in Arctic Norway: An investigation of the typology using multiple correspondence analysis. In T. Madsen (Ed.), *Multivariate archaeology: Numerical approaches to Scandinavian archaeology (pp. 71–84)* Aarhus.

Engelstad, E. (1989). Mesolithic house sites in arctic Norway. In C. Bonsall (Ed.), *The Mesolithic Europe: Papers Presented at the Third International Symposium in Edinburgh 1985* (pp. 331–337). Edinurgh: John Donald.

Engelstad, E. (1990). The meaning of sedentism and mobility in an archaeological and historic context. *Acta Borealia, 7*(2), 21–35. https://doi.org/10.1080/08003839008580388.

Erlandson, J. M. (2001). The Archaeology of Aquatic Adaptations: Paradigms for a New Millennium. *Journal of Archaeological Research, 9*(4), 287–350. https://doi.org/10.1023/A:1013062712695.

Fagen, R. (1987). A generalized habitat matching rule. *Evolutionary Ecology, 1*(1), 5–10. https://doi.org/10.1007/BF02067264.

Fisher, L. E. (2006). Blades and microliths: Changing contexts of tool production from Magdalenian to Early Mesolithic in southern Germany. *Journal of Anthropological Archaeology, 25*(2), 226–238. https://doi.org/10.1016/j.jaa.2005.09.005.

Fitzhugh, B. (2001). Risk and Invention in Human Technological Evolution. *Journal of Anthropological Archaeology, 20*(2), 125–167. https://doi.org/10.1006/jaar.2001.0380.

Fitzhugh, B. (2003). The evolution of complex hunter-gatherers. In The evolution of complex hunter-gatherers (pp. 1–10). Springer, Boston, MA. https://doi.org/10.1007/978-1-4615-0137-4_1

Fitzhugh, B. (2004). Colonizing the Kodiak Archipelago: Trends in raw material use and lithic technologies at the Tanginak Spring Site. *Arctic Anthropology, 41*(1), 14–40.

Fitzhugh, B. (2016). The origins and development of Arctic maritime adaptations in the subarctic and arctic Pacific. *The Oxford Handbook of the prehistoric arctic*. https://doi.org/10.1093/oxfordhb/9780199766956.013.20.

Fitzhugh, W. (1974). Ground slates in the Scandinavian Younger Stone Age with reference to circumpolar maritime adaptations. *Proceedings of the Prehistoric Society*, *40*, 45–58. https://doi.org/10.1017/S0079497X00011300.

Fitzhugh, W. (1975). A comparative approach to northern maritime adaptations. In W. Fitzhugh (Ed.), *Prehistoric maritime adaptations of the circumpolar zone* (pp. 339–386). The Hague: Mouton Publishers.

Fitzhugh, W. (2002). Yamal to Greenland: Global connections in circumpolar archaeology. In B. Cuncliffe, W. Davies, & C. Renfrew (Eds.), *Archaeology: The widening debate* (pp. 91–144). Oxford: Oxford University Press.

Foley, R. (1985). Optimality theory in anthropology. *Man, 20*(2), 222–242. https://doi.org/10.2307/2802382.

Freeman, J. (2016). The socioecology of territory size and a “work-around” hypothesis for the adoption of farming. *PLOS ONE, 11*(7), e0158743. https://doi.org/10.1371/journal.pone.0158743.

Freeman, J., & Anderies, J. M. (2012). Intensification, tipping points, and social change in a coupled forager-resource system. *Human Nature, 23*(4), 419–446. https://doi.org/10.1007/s12110-012-9154-8.

Fretwell, S. D. (1972). *Populations in a seasonal environment*. Princeton University Press.

Frink, L., Hoffman, B. W., & Shaw, R. D. (2003). Ulu Knife Use in Western Alaska: A comparative ethnoarchaeological study. *Current Anthropology, 44*(1), 116–122. https://doi.org/10.1086/345688.

Gjerde, J. M. S. (2017). A boat jouney in rock art 'from the Bronze Age to the Stone Age—from the Stone Age to the Bronze Age'in northernmost Europe. In P. Skoglund, J. Ling, & U. Bertilsson (Eds.), *North meets south: Theoretical aspects on the northern and southern rock art traditions in Scandinavia* (pp. 113–143). https://doi.org/10.2307/j.ctvh1dpgg.9 .

Gjerde, J. M. S. (2018). Marine mammals in the rock art of Alta, Norway, Northernmost Europe. In *Whale on the Rock II* / 한국의 사미 *II* (pp. 193–208). Ulsan: Ulsan Petroglyph Museum.

Gjerde, J. M. S., & Hole, J. T. (2013). *Tønsnes Havn, Tromsø kommune, Troms. Rapport frå dei arkeologiske undersøkingane 2011 og 2012*. UiT Norges arktiske universitet. http://www.ub.uit.no/munin/handle/10037/5837.

Gjessing, G. (1935). *Fra steinalder til jernalder i Finnmark: etnologiske problemer - Nasjonalbiblioteket*. Det Mallingske Bogtrykkeri.

Gjessing, G. (1942). *Yngre steinalder i Nord-Norge*. H. Aschehoug & Company.

Gjessing, G. (1943). *Træn-funnene*. H. Aschehoug & Company.

Gjessing, G. (1944). Circumpolar Stone Age. *Acta Arctica*, *Fasc. II*, 110–110.

Gjessing, G. (1953). The circumpolar Stone Age. *Antiquity, 27*(107), 131–136. https://doi.org/10.1017/S0003598X00024765.

Gjessing, H. (1920). *Rogalands stenalder*. Stavanger: Dreyer.

Graesch, A. P. (2007). Modeling ground slate knife production and implications for the study of household labor contributions to salmon fishing on the Pacific Northwest Coast. *Journal of Anthropological Archaeology, 26*(4), 576–606. https://doi.org/10.1016/j.jaa.2007.07.001.

Grønnow, B. (2017). *The Frozen Saqqaq Sites of Disko Bay, West Greenland - Qeqertasussuk and Qajaa (2400-900 BC): Studies of Saqqaq Material Culture in an Eastern Arctic Perspective*. Museum Tusculanum Press.

Günther, T., Malmström, H., Svensson, E. M., Omrak, A., Sánchez-Quinto, F., Kılınç, G. M., Krzewińska, M., Eriksson, G., Fraser, M., Edlund, H., Munters, A. R., Coutinho, A., Simões, L. G., Vicente, M., Sjölander, A., Jansen Sellevold, B., Jørgensen, R., Claes, P., Shriver, M. D., Valdiosera, C., Netea, M. G., Apel, J., Lidén, K., Skar, B., Storå, J., Götherström, A., & Jakobsson, M. (2018). Population genomics of Mesolithic Scandinavia: Investigating early postglacial migration routes and high-latitude adaptation. *PLOS Biology, 16*(1), e2003703. https://doi.org/10.1371/journal.pbio.2003703.

Gurven, M. D., & Davison, R. J. (2019). Periodic catastrophes over human evolutionary history are necessary to explain the forager population paradox. *Proceedings of the National Academy of Sciences, 116*(26), 201902406–201912766. https://doi.org/10.1073/pnas.1902406116.

Hallgren, F. (in press). In another part of western Jämtland. On raw material extraction, manufacture and circulation of knifes of red and green slate in the Stone Age of Northern Scandinavia. In J. Apel & L. Sundström (Eds.), 67 Years of Stone Age Research – The Kjel Knutsson Legacy. Uppsala, Sweden: (accepted manuscript).

Hallgren, F. (2012). A permeable border – Long-distance contacts between hunters and farmers in the Early Neolithic of Scandinavia. In Charlotte B. Damm & J. Saarikivi (Eds.), Networks, Interaction and Emerging Identities in Fennoscandia and Beyond. Papers from the Conference held in Tromsø, Norway, October 13-16 2009. (pp. 139–154). Helsinki, Finland: Suomalais-Ugrilainen Seura / Finno-Ugrian Society.

Halstead, P., & O'Shea, J. (1989). Introduction: Cultural responses to risk and uncertainty. *In Bad year economics: Cultural responses to risk and uncertainty*. https://doi.org/10.1017/CBO9780511521218.002.

Hammel, E. A. (2005). Chayanov revisited: A model for the economics of complex kin units. *Proceedings of the National Academy of Sciences, 102*(19), 7043–7046. https://doi.org/10.1073/pnas.0501987102.

Hansen, L. I. (2009). Networks, diversity and mobility among the Northern Sámi in the 16th Century. *Mémoires de la Société Finno-Ougrienne, 265*, 217–239.

Hansen, L. I. (2018). *The Sámi, state subjugation and strategic interaction - individual mobility within multicultural networks*. Novus.

Hayden, B. (1987). From Chopper to Celt: The evolution of resharpening techniques. *Lithic Technology, 16*(2–3), 33–43. https://doi.org/10.1080/01977261.1987.11720881.

Heath, J. (2004). *Eastern arctic kayaks: History, design, technique* (1st ed.). Fairbanks, AK: University of Alaska Press.

Heizer, R. F. (1943). Aconite poison whaling in Asia and America: an Aleutian transfer to the New World. Washington, D.C: US Government Printing Office.

Helberg, B. H. (1993). *Fiskeriteknologi som uttrykk for sosial tilhørighet: en studie av nordnorsk fiske i perioden 400-1700 e.Kr.* (Mag. Art.). University of Tromsø, Institute of Social Science, Department of Archaeology, Tromsø.

Helskog, K. (1985). Boats and meaning: A study of change and continuity in the Alta fjord, arctic Norway, from 4200 to 500 years B.C. *Journal of Anthropological Archaeology, 4*(3), 177–205. https://doi.org/10.1016/0278-4165(85)90002-9.

Helskog, K. (2012). Helleristninger av båter og ressursutnyttelse i Europas nordlige ytterkant. In F. Kaul & L. Sørensen (Eds.), *Nordlige verdener: Agrarsamfundenes ekspansion i nord* (pp. 221–232). Presented at the Nordlige verdener—agrarsamfundenes ekspansion i nord. Symposium p\a a Tanums Hällristningsmuseum, Underslös, Bohuslän, Copenhagen: Nasjonalmuseet.

Henrich, J. (2004). Demography and cultural evolution: How adaptive cultural processes can produce maladaptive losses: The Tasmanian case. *American Antiquity, 69*(2), 197–214. https://doi.org/10.2307/4128416.

Henriksen, S., & Valen, C. R. (2013). *Skjærvika og Fjellvika, Hammerfest kommune. Rapport fra de arkeologiske undersøkelsene 2009 og 2010.* The Arctic University Museum, Tromsø, Norway.

Hesjedal, A., Damm, C., Olsen, B., & Storli, I. (1996). *Arkeologi på Slettnes: dokumentasjon av 11.000 års bosetning*. Tromsø: Tromsø museum.

Hesjedal, A., Ramstad, M., & Niemi, A. R. (2009). *Undersøkelsene på Melkøya: Melkøyaprosjektet - kulturhistoriske registreringer og utgravninger 2001 og 2002*. Tromsø: Tromsø museum.

Hill, J. B., Clark, J., Doelle, W. H., & Lyons, P. D. (2010). Depopulation of the northern southwest: A macroregional perspective. In T. A. Kohler, M. D. Varien, & A. M. Wright (Eds.), Leaving Mesa Verde: Peril and change in the thirteenth-century southwest (pp. 34–52). University of Arizona Press.

Hinsch, E. (1957). «Saging» av skifer. *Finska Fornminnesföreningens tidskrift (SMYA-FET), 58*, 41–60.

Hirth, K. G. (1996). Political economy and archaeology: Perspectives on exchange and production. *Journal of Archaeological Research, 4*(3), 203–239.

Hodgetts, L. (2010). Subsistence diversity in the Younger Stone Age landscape of Varangerfjord, northern Norway. *Antiquity, 84*(323), 41–54. https://doi.org/10.1017/S0003598X00099750.

Holdberg, E., & Røskaft, M. (2015). *Håløygriket (Nordlands historie 1 - før 1600)* (1st ed.) Fagbokforlaget.

Hood, B. C. (In press). Settlement models for interior Finnmark. In M. Skandfer, H. P. Blankholm, & B. C. Hood (Eds.), Archaeological perspectives on hunter-gatherer landscapes and resource management in interior North Norway. Sheffield: Equinox.

Hood, B. C. (1992). *Prehistoric Foragers of the North Atlantic: Perspectives on Lithic Procurement and Social Complexity in the North Norwegian Stone Age and the Labrador Maritime Archaic (Docotorcal dissertation)*. University of Massachusetts.

Hood, B. C. (2012). The empty quarter? Identifying the Mesolithic of interior Finnmark, North Norway. *Arctic Anthropology, 49*(1), 105–135. https://doi.org/10.1353/arc.2012.0009.

Hood, B. C. (2015). Framing Sámi entanglement in Early Modern Colonial processes: Ethnohistorical and archaeological perspectives from interior North Norway. *Arctic Anthropology, 52*(2), 37–56.

Hood, B. C., Blankholm, H. P., & Skandfer, M. (In press). Conclusion: Resource management and landscape use in a long-term perspective. In M. Skandfer, H. P. Blankholm, & B. C. Hood (Eds.), Archaeological perspectives on hunter-gatherer landscapes and resource management in interior North Norway. Sheffield: Equinox.

Hood, B. C., & Helama, S. (2010). *Karlebotnbakken reloaded: shifting the chronological significance of an iconic late stone age site in Varangerfjord, North Norway* (pp. 35–43). *XXVII*: *Fennoscandia Archaeologica.*

Hooper, P. L., Demps, K., Gurven, M., Gerkey, D., & Kaplan, H. S. (2015). Skills, division of labour and economies of scale among Amazonian hunters and South Indian honey collectors. *Philosophical Transactions of the Royal Society B: Biological Sciences, 370*(1683), 20150008. https://doi.org/10.1098/rstb.2015.0008.

Hultgreen, T. (1988). *Yngre steinalder i Rana: en analyse av kyst og innlandsbosetninga mellom 4000-2000 BC.* (Magister dissertation). Tromsø University.

Huurre, M. (1983). *Pohjois-Pohjanmaan ja Lapin historia I - Pohjois-Pohjanmaan ja Lapin esihistoria*. Kuusamo.

Johnstone, P. (1972). Bronze Age sea trial. *Antiquity, 46*(184), 269–274.

Jørgensen, E. K. (2018). The palaeodemographic and environmental dynamics of prehistoric Arctic Norway: An overview of human-climate covariation. *Quaternary International*. https://doi.org/10.1016/j.quaint.2018.05.014.

Jørgensen, E. K., Pesonen, P., & Tallavaara, M. (2020). Climatic changes cause synchronous population dynamics and adaptive strategies among coastal hunter-gatherers in Holocene northern Europe. *Quaternary Research*, 1–16. https://doi.org/10.1017/qua.2019.86.

Jørgensen, E. K., & 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. *The Holocene, 29*(11), 1782–1800. https://doi.org/10.1177/0959683619862036.

Jørgensen, R. (2010). *Production or trade? The supply of iron to North Norway during the Iron Age*. Universitetet i Tromsø https://munin.uit.no/handle/10037/2487. .

Kelly, D. R. L. (2013). The lifeways of hunter-gatherers: The foraging spectrum (2nd Revised ed. edition.). Cambridge: Cambridge University Press.

Kiseleva, A., & Murashkin, A. (2019). Marine hunting and fishing on the coast of north Fennoscandia before Christ (in Russian). МОРСКАЯ ОХОТА И РЫБОЛОВСТВО НА ПОБЕРЕЖЬЕ СЕВЕРНОЙ ФЕННОСКАНДИИ ДО РУБЕЖА ЭР, *27*(2), 171–179. 10.24411/2309-4370-2019-12212

Kriiska, A. (2015). Foreign materials and artefacts in the 4th and 3rd millennia BCE Estonian Comb Ware Complex. In *When Gods Spoke.* Researches and reflections on religious phenomena and artefacts. *Studia in honorem Tarmo Kulmar* (p. 107−124). Tartu.

Langejans, G. H. J., van Niekerk, K. L., Dusseldorp, G. L., & Thackeray, J. F. (2012). Middle Stone Age shellfish exploitation: Potential indications for mass collecting and resource intensification at Blombos Cave and Klasies River, South Africa. *Quaternary International, 270*, 80–94. https://doi.org/10.1016/j.quaint.2011.09.003.

Luho, V. (1967). *Die Suomusjärvi-Kultur: die mittel-und spätmesolithische Zeit in Finnland* (Vol. 66).

Lundberg, Å. (1997). *Vinterbyar: ett bandsamhälles territorier i Norrlands inland, 4500-2500 f. Kr.* (Studia Archaeologica Universitatis Umensis 8.). Umeå.

Madsen, D. B., & Schmitt, D. N. (1998). Mass collecting and the diet breadth model: A great basin example. *Journal of Archaeological Science, 25*(5), 445–455. https://doi.org/10.1006/jasc.1997.0245.

Manclossi, F., Rosen, S. A., & Boëda, E. (2019). From stone to metal: The dynamics of technological change in the decline of chipped stone tool production. A case study from the southern Levant (5th–1st Millennia BCE). *Journal of Archaeological Method and Theory, 26*(4), 1276–1326. https://doi.org/10.1007/s10816-019-09412-2.

Mansrud, A., & Persson, P. (2018). Waterworld: Environment, animal exploitation, and fishhook technology in the north-eastern Skagerrak area during the Early and Middle Mesolithic (9500–6300 cal BC). In P. Persson, F. Riede, B. Skar, H. M. Breivik, & L. Jonsson (Eds.), Ecology of early settlement in Northern Europe - Conditions for subsistence and survival (Vol. 1, pp. 129–166). Equinox.

Marciniak, A. (2011). The secondary products revolution: Empirical evidence and its current zooarchaeological critique. *Journal of World Prehistory, 24*(2), 117–130. https://doi.org/10.1007/s10963-011-9045-7.

Marstrander, S. (1976). Building a hide boat. An archaeological experiment. *International Journal of Nautical Archaeology, 5*(1), 13–22.

Martens, V. V., Myrvoll, E. R., Bergersen, O., Vorenhout, M., Sandvik, P. U., & Denham, S. (2017). *InSituFarms. Archaeological Deposits in a Changing Climate Case Baŋkgohppi, Unjárgga gielda/ Nesseby k., Finnmark* (No. NIKU reports 77).

Matiskainen, H. (1989). *Studies on the chronology, material culture and subsistence economy of the Finnish mesolithic, 10 000-6000 b.p.* Vammala: Vammalan Kirjapaino Oy.

Meinander, C. F. (1964). Skifferknivar med djurhovudskaft. *Finskt Museum, 71*, 5–33.

Miettinen, A., Sarmaja-Korjonen, K., Sonninen, E., Junger, H., Lempiäinen, T., Ylikoski, K., et al. (2008). The palaeoenvironment of the 'Antrea net find'. In *Karelian Isthmus* (pp. 71–97). Helsinki: Finnish Antiquarian Society.

Minc, L. D., & Smith, K. P. (1989). The spirit of survival: Cultural responses to resource variability in North Alaska. In P. Halstead & J. M. O'Shea (Eds.), *Bad year economics: Cultural responses to risk and uncertainty* (pp. 8–39). Cambridge: Cambridge University Press.

Morgan, C. (2015). Is it intensification yet? Current archaeological perspectives on the evolution of hunter-gatherer economies. *Journal of Archaeological Research, 23*(2), 163–213. https://doi.org/10.1007/s10814-014-9079-3.

Morin, J. (2004). Cutting edges and salmon skin: Variation in salmon processing technology on the northwest coast. *Canadian Journal of Archaeology / Journal Canadien d'Archéologie, 28*(2), 281–318.

Moss, M. L. (2004). The status of archaeology and archaeological practice in southeast Alaska in relation to the larger northwest coast. *Arctic Anthropology, 41*(2), 177–196. https://doi.org/10.1353/arc.2011.0001.

Munch, J. S. (1962). *Boplasser med asbestkeramikk på Helgelandskysten - Nasjonalbiblioteket*. Oslo.

Murashkin, A., Kolpakov, E. M., Shumkin, V. Y., Khartanovich, V. I., & Moiseyev, V. G. (2016). Kola Oleneostrovskiy grave field: A unique burial site in the European Arctic. *«New Sites, New Methods». The Finnish Antiquarian Society, 21*, 187–199.

Niemi, A. R., & Oppvang, J. (2018). *Nyelv Nedre Vest, Nesseby k., Finnmark f. - Utgravning av hustuft og boplassområde fra yngre steinalder (No. 46) (p. 123)*. Tromsø, Norway: Tromsø Museum - Universitetsmuseet.

Nordqvist, K. (2018). *The Stone Age of north-eastern Europe 5500–1800 calBC: bridging the gap between the East and the West*. Oulu: University of Oulu.

Nuñez, M. (1998). Slates, the "plastics" of Stone Age Finland. In L. Holm & K. Knutsson (Eds.), Proceedings from the Third Flint Alternatives Conference at Uppsala, Sweden, October 18-20*, 1996* (Vol. 16, pp. 105–124). Presented at the The Third Flint Alternatives Conference, Uppsala, Sweden: Department of Archaeology and Ancient History, Uppsala University.

Nygaard, S. E. (1989). The Stone Age of northern Scandinavia: A review. *Journal of World Prehistory, 3*(1), 71–116.

Nyland, A. J. (2017). Materialised taskscapes? Mesolithic lithic procurement in southern Norway. In U. Sujala & P. Mills (Eds.), *Forms of Dwelling: 20 years of Taskscapes in archaeology* (pp. 125–150). Oxford: Oxbow Books.

O'Brien, M. J., & Bentley, R. A. (2011). Stimulated variation and cascades: Two processes in the evolution of complex technological systems. *Journal of Archaeological Method and Theory, 18*(4), 309–335.

Olofsson, A. (2003). *Pioneer settlement in the Mesolithic of northern Sweden*. Umeå: Umeå University, Dept. of Archaeology and Sami Studies.

Olofsson, A. (2015). *Lithics and Culture in the Stone Age of Northern Fennoscandia: techno-cultural aspects of northern hunter-gatherers with special reference to stone tool technology in northern Sweden 4500-3500 BC*. Umeå universitet.

Olsen, B. (1984). *Stabilitet og endring: produksjon og samfunn i Varanger 800 f.Kr - 1700 e.Kr* (Mag. Art.). University of Tromsø, Institute of Social Science, Department of Archaeology, Tromsø.

Olsen, B. (1994). *Bosetning og samfunn i Finnmarks forhistorie*. Oslo: Universitetsforlaget.

Olsen, H. (1967). *Varanger-Funnene IV: osteologisk Materiale: innledning- Fisk -Fugl*. Universitetsforlaget.

Osborn, A. J. (2004). Poison hunting strategies and the organization of technology in the circumpolar region. In A. Johnson (Ed.), *Processual archaeology: Exploring analytical strategies, frames of reference, and culture process* (pp. 134–191). Westport, CT: Praeger Publishers.

Page, A. E., Viguier, S., Dyble, M., Smith, D., Chaudhary, N., Salali, G. D., Thompson, J., Vinicius, L., Mace, R., & Migliano, A. B. (2016). Reproductive trade-offs in extant hunter-gatherers suggest adaptive mechanism for the Neolithic expansion. *Proceedings of the National Academy of Sciences, 113*(17), 4694–4699. https://doi.org/10.1073/pnas.1524031113.

Pargeter, J., & Shea, J. J. (2019). Going big versus going small: Lithic miniaturization in hominin lithic technology. *Evolutionary Anthropology: Issues, News, and Reviews, 28*(2), 72–85. https://doi.org/10.1002/evan.21775.

Pearson, H. W. (1957). The economy has no surplus: critique of a theory of development. In M. Polanyi, C. Arensberg, & H. W. Pearson (Eds.), *Trade and market in the early empires* (pp. 320–341). Chicago: Henry Regnery Company.

Pedersen, H. C. (1986). *Skinboats of Greenland*. Roskilde: Viking Ship Museum.

Perdikaris, S. (1999). From chiefly provisioning to commercial fishery: Long-term economic change in Arctic Norway. *World Archaeology, 30*(3), 388–402. https://doi.org/10.1080/00438243.1999.9980419.

Phillips, D. A., Wearing, H. J., & Clark, J. J. (2018). Village growth, emerging infectious disease, and the end of the Neolithic demographic transition in the southwest United States and northwest Mexico. *American Antiquity, 83*(2), 263–280. https://doi.org/10.1017/aaq.2018.3.

Piperno, D. R. (2011). The origins of plant cultivation and domestication in the new world tropics: Patterns, process, and new developments. *Current Anthropology, 52*(S4), S453–S470. https://doi.org/10.1086/659998.

Piperno, D. R., & Pearsall, D. M. (1998). *The origins of agriculture in the lowland neotropics* (1st ed.). San Diego: Emerald Group Pub Ltd..

Development Core Team, R. (2015). R: a language and environment for statistical computing. *Vienna, Austria: the R Foundation for Statistical Computing*. http://www.gbif.org/resource/81287. .

Rankama, T. (1986). A group of Late Stone Age slate arrowheads from northernmost Finland and Norway. *Iskos, 6*, 127–139.

Read, D. (2008). An interaction model for resource implement complexity based on risk and number of annual moves. *American Antiquity, 73*(4), 599–625. https://doi.org/10.2307/25470520.

Renouf, M. A. P. (1986). Excavations at a Younger Stone Age settlement in Varangerfjord, Norway. *Polar Record, 23*(144), 273–288. https://doi.org/10.1017/S0032247400007105.

Renouf, M. A. P. (1989). Prehistoric hunter-fishers of Varangerfjord, northeastern Norway: Reconstruction of settlement and subsistence during the Younger Stone Age. British Archaeological Reports.

Renouf, M. A. P., & Bell, T. (2008). Dorset Palaeoeskimo skin processing at Phillip's Garden, Port au Choix, northwestern Newfoundland. *Arctic, 61*(1), 35–47.

Riede, F., Høye, T. T., Tejsner, P., Veldhuis, D., & Willerslev, R. (2018). Special section introduction: Socioecological disequilibrium in the circumpolar north. *Human Ecology, 46*(5), 615–620. https://doi.org/10.1007/s10745-018-0009-8.

Ritchie, K., Hufthammer, A. K., & Bergsvik, K. A. (2016). Fjord fishing in Mesolithic Western Norway. *Environmental Archaeology, 21*(4), 309–316. https://doi.org/10.1080/14614103.2015.1118212.

Ritchie, W. A. (1969). Ground slates: East and west. *American Antiquity, 34*(4), 385–391. https://doi.org/10.2307/277735.

Ritsumeikan. (2007). *Stone tools of the Mumun Pottery Period in Korea [Korean original]*. Ritsumeikan University.

Sahlins, M. (1972). *Stone Age economics* (1st ed.). New Brunswick, NJ: Aldine Transaction.

Schanche, K. (1988). *Mortensnes, en boplass i Varanger: en studie av samfunn og materiell kultur gjennom 10.000 år* (Mag. Art.). University of Tromsø, Institute of Social Science, Department of Archaeology, Tromsø.

Schanche, K. (1989). *Nye funn fra yngre steinalder i Varanger* (pp. 53–71). *LII*: *Viking*.

Sheehan, G. W. (1985). 5 - Whaling as an organizing focus in northwestern Alaskan Eskimo Society. In T. D. Price & J. A. Brown (Eds.), Prehistoric hunters-gatherers (pp. 123–154). Academic Press. https://doi.org/10.1016/B978-0-12-564750-2.50010-X

Shennan, S., Downey, S. S., Timpson, A., Edinborough, K., Colledge, S., Kerig, T., Manning, K., & Thomas, M. G. (2013). Regional population collapse followed initial agriculture booms in mid-Holocene Europe. *Nature Communications, 4*(1), *4*.

Shennan, S., & Edinborough, K. (2007). Prehistoric population history: From the Late Glacial to the Late Neolithic in Central and Northern Europe. *Journal of Archaeological Science, 34*(8), 1339–1345. https://doi.org/10.1016/j.jas.2006.10.031.

Sherratt, A. (1981). *Plough and pastoralism: Aspects of the secondary products revolution*. Cambrdge University Press.

Sherratt, A. (1983). The secondary exploitation of animals in the Old World. *World Archaeology, 15*(1), 90–104. https://doi.org/10.1080/00438243.1983.9979887.

Simonsen, P. (1956). Nye Fund af stenalderbopladser i Troms. *Acta Borealia, 4*, 1–132.

Simonsen, P. (1961). *Varanger-funnene II Fund og udgravninger på fjordens sydkyst* (Vol. VII). Tromsø: Tromsø Museum.

Simonsen, P. (1975). When and why did occupational specialization begin at the Scandinavian north coast. In Prehistoric maritime adaptations of the circumpolar zone (pp. 75–86).

Simonsen, P. (1976). *Veidemenn på Nordkalotten. Hefte 2: Yngre steinalder*. Tromsø: Institutt for samfunnsvitenskap, Universitetet i Tromsø.

Simonsen, P. (1996). *Steinalderbosetningen i sandbukt på Sørøya, Vest-Finnmark: rapport og tolkning*. Tromsø Museum.

Sjögren, P., & Arntzen, J. E. (2013). Agricultural practices in Arctic Norway during the first millennium b.c. *Vegetation History and Archaeobotany, 22*(1), 1–15. https://doi.org/10.1007/s00334-012-0346-2.

Sjögren, P., & Damm, C. (2019). Holocene vegetation change in northernmost Fennoscandia and the impact on prehistoric foragers 12 000–2000 cal. a BP – A review. *Boreas, 48*(1), 20–35. https://doi.org/10.1111/bor.12344.

Skandfer, M. (2003). *Tidlig, nordlig kamkeramikk: typologi, kronologi, kultur*. PhD-dissertation. Universitetet i Tromsø.

Skandfer, M. (2005). *Early, Northern Comb Ware in Finnmark: The Concept of Säräisniemi 1 reconsidered* (pp. 3–27). *XXII*: *Fennoscandia Archaeologica*.

Skandfer, M. (2009). "All change"? Exploring the role of technological choice in the Early Northern Comb Ware of Finnmark, Arctic Norway. In P. Jordan & M. Zvelebil (Eds.), *Ceramics before farming. The dispersal of pottery among prehistoric Eurasian hunter-gaterers (pp. 347–374)*. Left Coast Press. https://doi.org/10.4324/9781315432373-22.

Smith, A. E. (1979a). Chayanov, Sahlins, and the labor-consumer balance. *Journal of Anthropological Research*, *35*(4), 477–480

Smith, E. A. (1979b). Human adaptation and energetic efficiency. *Human Ecology, 7*(1), 53–74.

Smith, E. A. (1987a). Optimization theory in anthropology: Applications and critiques. In *The latest on the best: Essays on evolution and optimality* (pp. 201–249). Cambridge, MA, US: The MIT Press.

Smith, E. A. (1987b). On fitness maximization, limited needs, and hunter-gatherer time allocation. *Ethology and Sociobiology, 8*(1), 73–85. https://doi.org/10.1016/0162-3095(87)90059-8.

Smith, M. E. (2004). The archaeology of ancient state economies. *Annual Review of Anthropology, 33*(1), 73–102. https://doi.org/10.1146/annurev.anthro.33.070203.144016.

Søborg, H. C. (1988). Knivskarpe grenser for skiferbruk i steinalderen. *Festskrift for Anders Hagen*, 225–241.

Solberg, O. (1911). Ein neuer eisenzeitlicher Fund aus Ostfinmarken in Norwegen: Praehistorische Zeitschrift. *Praehistorische Zeitschrift*, *3*(1), 347–355. https://doi.org/10.1515/prhz-1911-0132

Sommerseth, I. (1997). Tidlige Skifergjenstander på Slettnes. Problemer omkring typologi, kronologi og fortidig mangfold. Mag.Art. University of Tromsø, Norway.

Star, B., Boessenkool, S., Gondek, A. T., Nikulina, E. A., Hufthammer, A. K., Pampoulie, C., Knutsen, H., André, C., Nistelberger, H. M., Dierking, J., Petereit, C., Heinrich, D., Jakobsen, K. S., Stenseth, N. C., Jentoft, S., & Barrett, J. H. (2017). Ancient DNA reveals the Arctic origin of Viking Age cod from Haithabu, Germany. *Proceedings of the National Academy of Sciences, 114*(34), 9152–9157. https://doi.org/10.1073/pnas.1710186114.

Stiner, M. C. (2001). Thirty years on the "broad spectrum revolution" and Paleolithic demography. *Proceedings of the National Academy of Sciences*, *98*(13), 6993–6996. https://doi.org/10.1073/pnas.121176198

Sundquist, Ø. (1999). Traces of iron production in prehistoric Finnmark. *Fennoscandia Archaeologica*, (XVI), 47–57.

Sutton, D. G., Anderson, A., Bowdler, S., Green, R. c., Krupnik, I. I., Lourandos, H., et al. (1982). Towards the recognition of convergent cultural adaptation in the subantarctic zone [with Comments and Replies]. *Current Anthropology, 23*(1), 77–97. https://doi.org/10.1086/202780.

Tainter, J. A. (2006). Archaeology of overshoot and collapse. *Annual Review of Anthropology, 35*(1), 59–74. https://doi.org/10.1146/annurev.anthro.35.081705.123136.

Tallavaara, M., & Pesonen, P. (2018). Human ecodynamics in the north-west coast of Finland 10,000–2000 years ago. *Quaternary International.* https://doi.org/10.1016/j.quaint.2018.06.032.

Tallavaara, M., Pesonen, P., & Oinonen, M. (2010). Prehistoric population history in eastern Fennoscandia. *Journal of Archaeological Science, 37*(2), 251–260. https://doi.org/10.1016/j.jas.2009.09.035.

Tallavaara, M., & Seppä, H. (2012). Did the mid-Holocene environmental changes cause the boom and bust of hunter-gatherer population size in eastern Fennoscandia? *The Holocene, 22*(2), 215–225. https://doi.org/10.1177/0959683611414937.

Tarasov, A. (2011). The technology of making slate macrotools at the Oleneostrovskaya Mesolithic camp-site (Russian). *Archaeological News*, *17*, 58–69.

Tarasov, A., & Stafeev, S. (2014). Estimating the scale of stone axe production: A case study from Onega Lake, Russian Karelia. *Journal of Lithic Studies, 1*(1), 239–261. https://doi.org/10.2218/jls.v1i1.757.

Thommessen, T. (1994). *FATIMA-prosjektet. Arkeologiske undersøkelser i Kåfjord og på Magerøya, Nordkapp kommune (No. 27)*. Tromsø, Norway: Tromsø Museum - Universitetsmuseet.

Timpson, A., Colledge, S., Crema, E., Edinborough, K., Kerig, T., Manning, K., Thomas, M. G., & Shennan, S. (2014). Reconstructing regional population fluctuations in the European Neolithic using radiocarbon dates: A new case-study using an improved method. *Journal of Archaeological Science, 52*, 549–557. https://doi.org/10.1016/j.jas.2014.08.011.

Torrence, R. (1983). Time budgeting and hunter-gatherer technology. In G Bailey (Ed.), Hunter-gatherer economy in prehistory: A European perspective (pp. 11–22). Cambridge: Cambridge University Press.

Tremayne, A. H., & Winterhalder, B. (2017). Large mammal biomass predicts the changing distribution of hunter-gatherer settlements in mid-late Holocene Alaska. *Journal of Anthropological Archaeology, 45*, 81–97. https://doi.org/10.1016/j.jaa.2016.11.006.

Ugan, A., Bright, J., & Rogers, A. (2003). When is technology worth the trouble? *Journal of Archaeological Science, 30*(10), 1315–1329. https://doi.org/10.1016/S0305-4403(03)00022-0.

Utne, A. (1973). *En veidekulturs boplass i Lofoten, Storbåthallaren ved Nappstraumen.* (Mag. Art.). University of Tromsø, Institute of Social Science, Department of Archaeology, Tromsø.

Vaesen, K., Collard, M., Cosgrove, R., & Roebroeks, W. (2016). Population size does not explain past changes in cultural complexity. *Proceedings of the National Academy of Sciences, 113*(16), E2241–E2247. https://doi.org/10.1073/pnas.1520288113.

Van de Noort, R. (2011). *North sea archaeologies: A maritime biography, 10,000 BC - AD 1500* (1st ed.). New York, NY: Oxford University Press.

Wilhelmsson, Å. (1996). *Skifferknivar - förekomst, utbredning och användning. Praktiska och teoretiska studier kring knivar från södra Norrland.* Sweden: Umeå.

Winterhalder, B. (2001). The behavioural ecology of hunter-gatherers. In C. Panter-Brick, R. H. Hayton, & P. Rowley-Conwy (Eds.), *Hunter-gatherers: An interdisciplinary perspective* (pp. 12–38). Cambridge: Cambrdge University Press.

Winterhalder, B., Baillargeon, W., Cappelletto, F., Randolph Daniel, I., & Prescott, C. (1988). The population ecology of hunter-gatherers and their prey. *Journal of Anthropological Archaeology, 7*(4), 289–328. https://doi.org/10.1016/0278-4165(88)90001-3.

Winterhalder, B., Kennett, D. J., Grote, M. N., & Bartruff, J. (2010). Ideal free settlement of California's Northern Channel Islands. *Journal of Anthropological Archaeology, 29*(4), 469–490. https://doi.org/10.1016/j.jaa.2010.07.001.

Yaragina, N. A., Aglen, A., & Sokolov, K. M. (2011). Cod. In T. Jacobsen & V. K. Ozhigin (Eds.), *The Barents Sea; Ecosystem, resources, management- half a century of Russian-Norwegian cooperation* (pp. 225–270). Trondheim, Norway: Tapir Academic Press.

Yesner, D. R., Ayres, W. S., Carlson, D. L., Davis, R. S., Dewar, R., Morales, M. R. G., et al. (1980). Maritime hunter-gatherers: Ecology and prehistory [and Comments and Reply]. *Current Anthropology, 21*(6), 727–750.

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.