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TIMING THE EMERGENCE AND DEVELOPMENT OF ARABLE FARMING IN SOUTHEASTERN NORWAY BY USING SUMMED PROBABILITY DISTRIBUTION OF RADIOCARBON DATES AND A BAYESIAN AGE MODEL

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ABSTRACT. The paper explores the emergence and development of arable farming in southeastern Norway by compiling and analyzing directly dated cereals from archaeological contexts. By using summed probability distributions of radiocarbon dates and Bayesian modeling, the paper presents the first comprehensive analysis of the directly dated evidence for farming in the region. The models provide a more precise temporal resolution to the development than hitherto presented. The results demonstrate that the introduction of arable farming to southeastern Norway was a long-term development including several steps. Three different stages are pointed out as important in the process of establishing arable farming: the Early and Middle Neolithic, the Late Neolithic, and the Early Iron Age.

KEYWORDS: Bayesian analysis, cereals, farming, radiocarbon dating, summed probability distribution.

INTRODUCTION

For several million years, humans and our ancestors relied on the gathering of wild plants, hunting of marine and terrestrial animals, and fishing for a living. This longstanding way of life changed around 12,000 years ago when human societies in different parts of the world started to domesticate a variety of plants and animals (Gibbs and Jordan 2016; Piperno 2018). Early crop growing and domestication mark a significant threshold in human history and the shift to early agro-pastoral lifeways correlates with fundamental changes in past human demography and social organization (Shennan 2018). The shift was not a rapid and straightforward transition from foraging to agriculture but a complex process with a variety of different temporal and regional developments and local adjustments according to ecology, environment and cultural forces (Gibbs and Jordan 2016; de Vareilles et al. 2020; Gron et al. 2020). The process of introducing new plants and domesticates lasted for several millennia and was made up of cycles of expansion and stasis (Bocquet-Appel et al. 2009; Silva and Vander Linden 2017).

Farming spread across Europe from ca. 10,000 cal BP and came to a halt in Northern Europe at 7500–7000 cal BP before continuing into southern Scandinavia, Britain, and Ireland around 6000 cal BP (Silva and Vander Linden 2017). The introduction of farming to Scandinavia demonstrates the complexity in the development and spread of early agro-pastoral lifeways (Gron and Sørensen 2018; Lewis et al. 2020). Shortly after 6000 cal BP, domesticated animals and cereals spread to an area stretching from Denmark and Scania in the south all the way up to the Åland Islands in the Baltic Sea (Hallgren 2008; Sjögren 2012; Sørensen and Karg 2014; Vanhanen et al. 2019). The impact and scale of early farming varied in different parts of Scandinavia. In Denmark and parts of Sweden charred cereals and bones from domesticated animals appear in archaeological contexts dated between 6000 and 5500 cal BP (Sørensen and Karg 2014). In southeastern Norway, which is the geographical focus of this paper, the archaeological record informs us of a different situation. As in

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other parts of Scandinavia, Funnel beaker-style pottery and polished flint axes occur immediately after 6000 cal BP (Glørstad 2009) but very little evidence of farming dates to the Early Neolithic period (ca. 5900–5200 cal BP). The only possible exceptions are cereal type pollen and pollen from grazing indicators such as ribwort plantain (*Plantago Lanceolata*) from bogs and lakes throughout southern Norway (e.g., Prøsch-Danielsen and Simonsen 2000; Wieckowska-Lüth et al. 2017), as well as a couple of charred cereals dated to the transition to the Middle Neolithic period (Reitan et al. 2018). While the presence of Early and Middle Neolithic farming in southern Norway is disputed there seems to be a consensus among researchers that farming became economically important in the Late Neolithic, from ca. 4400 to 4300 cal BP (Prescott 1996; Prøsch-Danielsen et al. 2018; Glørstad et al. 2020; Prescott 2020). From this period, there is a continuous presence of agriculture, with crop growing and domesticated animals constituting the backbone of the economy for a very long time.

The limited evidence of farming in the Early and Middle Neolithic has caused debate in Norwegian archaeology as to how to understand the introduction of farming (e.g., Helle et al. 2006; Glørstad 2009; Bergsvik et al. 2020). Critical evaluation has dismissed the vague indications on farming found within predominantly foraging societies (Prescott 1996, 2020). Consequently, it is stressed that we must consider the "weak" data in order to identify low-level agriculture or small-scale gardening practiced among hunter-gatherers (Bergsvik et al. 2020: 358). Still, when it comes to identifying early farming, "weak" data or indirect evidence such as single pollen evidence of cereal type must be treated with caution (Behre 2007: 215–216) and should be backed by more solid empirical evidence such as bones from domesticates or cultivated plants such as cereals.

To date, southeastern Norway has lacked a comprehensive analysis of directly dated evidence for farming. This paper aims to investigate the temporal development in the introduction and establishment of arable farming in southeastern Norway based on aggregated data of radiocarbon-dated charred cereal grains. This aim has two motivations. First, it will provide new insight on the agricultural transition by breaking down the longer process into shorter time steps. Second, precise estimates of the timescale of this long-term process will refine our understanding of local scale dynamics as well as highlight the diversity in this major shift on a global scale.

Regional Setting

The region under study consists of the southern and southeastern parts of Norway (58°–61°N). The Scandinavian Ice Shield covered most of the region until ca. 11,500 cal BP and the marine limit varies between 220 m and 5 m above present sea level (Bergstrøm 1999; Romundset et al. 2019). There has been a continuous postglacial land upheaval around the Oslo fjord, and during the mid- and late Holocene, increasingly more land was exposed. The situation is different for the southernmost part where a mid-Holocene transgression occurred between 8500 and 7000 cal BP (Romundset et al. 2015).

A long and varied coastline characterizes this region. The topography varies considerably and the region consists of several vegetation zones. The coastal area has temperate climate with deciduous forest. The inland has a dry climate and coniferous forest while the alpine regions have a subarctic climate with birch and alpine vegetation. Most of the areas that constitute today's fertile and arable soils in the lowlands consist mainly of marine deposits,

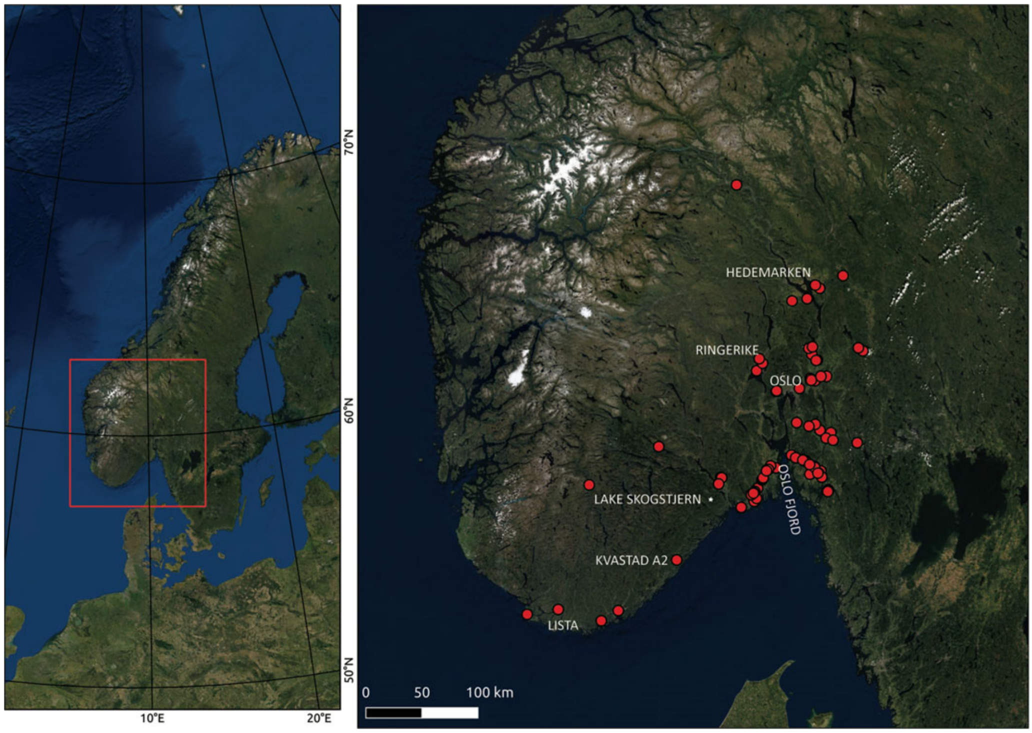

Figure 1 Map showing the geographical distribution of all sites with dated cereal grains included in the analysis. Background map from Esri. Map by Isak Roalkvam. Modified by author.

moraine or river sediments. These were situated below sea level in the mid-Holocene and did not become available for settlement and farming until the Middle and Late Neolithic, but regional variation occurred. Less than 3% of Norway is fully cultivated, but cultivated areas exist all over the country with the best conditions for crop growing found around the Oslo Fjord, southeastern Norway, in Rogaland, southwestern Norway and in Trøndelag, central Norway. The length of the growing season shifts according to geographical location and altitude, and the present number of growing degree-days are between 1200 and 1500 in the best agricultural areas (Skaugen and Tveito 2002). Areas for rough grazing are substantially larger and grazing in forests and mountains has been an essential part of Norwegian food production for a long time.

Data

The dataset consists of radiocarbon-dated cereals from archaeological contexts in southeastern Norway (Figure 1). This is the first comprehensive overview of directly dated charred cereals in the region. All samples were collected from a range of CRM excavations carried out by the Museum of Cultural History, University of Oslo. Every effort has been carried out to make this dataset as complete as possible by searching through available excavation reports and published literature. Most likely, the dataset does not include all dated cereals, but the majority of dated samples are included and the dataset is representative for the empirical situation of today.

Excavation-, sampling- and dating strategies can bias the information related to the occurrence of cereal types. The relative distribution of type of cereals included here is not representative

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of the distribution of cereals types in the total assemblage as the majority of cereals grains collected at archaeological excavations are undated (cf. Bårdseth and Sandvik 2010: 3284–3286). Dating strategies most often focus on dating the anthropogenic features or contexts in which the cereals were found, rather than aiming to date the cereals themselves to obtain information on temporal distribution of cereal types.

Preservation conditions in the region cause challenges for retrieval and identification of cereals and macrobotanical remains. Macrobotanical remains occur sporadically and become rarer with increasing age. Post-depositional processes have an effect on the morphology of the cereals making determination to type difficult (Soltvedt and Enevold 2008: 60) and in many circumstances, a detailed determination to species and genus has been impossible due to the condition of the cereals (e.g., Sandvik 2008: 62; Viklund et al. 2013: 67). A general rule is that the oldest cereals are the hardest to identify to species as they often are fragmented and in a poor condition (Dincauze 2000: 334).

All cereal grains included in this analysis are charred. Cereals have high levels of starch and can absorb heat and carbonize at a slow rate without being completely burned and oxidized. Thus, the carbonization process preserves the cereals. At the same time, the carbonization process can affect the shape of the cereals and act like a selection process as cereals have low resistance to temperatures above 400°C. Too high temperatures will cause a total combustion of the cereals (Sandvik 2008: 76; Dincauze 2000: 334).

In sum, 615 radiocarbon dates of charred cereal grains from 91 sites are included. All samples with additional information are presented as supplementary material. The dated samples are distributed relatively evenly across large parts of southeastern Norway. Most samples are from the fertile lowlands around the Oslo Fjord, especially from Vestfold, Østfold, and Akershus, and northwards to Ringerike and Hedemarken (cf. Figure 1). Limited excavations of sites located on easily workable arable soils suitable for early farming as well as excavation methods can affect the amount of cereals dated to the Neolithic period. As I argue below, this however does not seem to be the case.

Four different cereal species are present in the dataset: Barley (*Hordeum* sp.), wheat (*Triticum* sp.), oat (*Avena* sp.) and rye (*Secale cereale*). Barley constitutes ca. 50% of the samples and is the most common type in the dataset, while wheat, rye and oats make up only a small portion of the assemblage (Table 1). Undetermined Cerealia counts for 41% of the samples.

METHODS

Summed Probability Distribution and Bayesian Modeling of Arable Farming in Southeastern Norway

In the last decades, the Museum of Cultural History has performed a large number of archaeological excavations, with focused strategies for sampling and analyzing macrobotanical remains including cereals. Direct dating of cereals has become a standard method when such material is available. Due to this, we have generated largely different and qualitatively better data than only a decade ago and a considerable amount of directly dated evidence for arable farming is now available. The radiocarbon-dated cereals have so far not been rigorously tested using proper methods at intra-site or inter-site levels in the region. The standard procedure has been calibration of single dates to calendar years followed by visual inspection of individual dates (Glørstad 2004; Bårdseth 2008) or by simple

Table 1 Overview of radiocarbon-dated cereal grains determined to type and species.

Cereal type	Species	Genus	Sum	Total	%
Oat	*Avena* sp.			16	3
Barley	*Hordeum vulgare*		234		
		Hordeum vulgare var. *vulgare*	45		
		Hordeum vulgare var. *nudum*	25		
				304	49
Rye	*Secale cereale*			4	0.6
Wheat	*Triticum*		19		
		Triticum dicocum	3		
		Triticum turgidum	4		
		Triticum aestivum/T. turgidum	1		
		Triticum aestivo/compactum	1		
		Triticum dicoccum/spelta	8		
		Triticum vulgare	6		
				42	7
Undetermined cereal	*Cerealia* sp.			251	41
Total				617	100

sum calibration to investigate temporal development within limited geographical areas (Gjerpe 2008). The problem with these approaches is that informal interpretations of calibrated radiocarbon age distributions might lead to misinterpretations caused by statistical scatter on the radiocarbon measurement and calibration effects (Bayliss et al. 2007: 5–6, 9; Bronk Ramsey 2009; Bayliss 2015; Hamilton and Krus 2018: 191). In order to develop high precision chronologies it is necessary to constrain the inherent scatter in the calibration process by applying formalized models by using Bayesian chronological modeling (Hamilton and Krus 2018; Finley et al. 2020). Simple sum calibration, on the other hand, provides good presentation of data but cannot be used to infer relative variation in human activity as it does not take issues like calibration effects or sampling error into account (Crema and Bevan 2020; Timpson et al. 2021).

Here I use these recently collected radiocarbon data on charred cereal samples to develop a summed probability distribution (SPD) and a Bayesian age model. The main aim is to examine local temporal developments in the introduction of arable farming. To do this an SPD of radiocarbon dates was developed using the *rcarbon* package (Crema and Bevan 2020) in *R* (R Core Team 2018). SPDs present the temporal distribution of a data set and the method has shown great promise in treating aggregated sets of radiocarbon dates as proxies for variation in human activity. The method follows the premise that there is a relation between human activity and datable components in the archaeological record (e.g., Rick 1987; Freeman et al. 2018). This dates-as-data approach implies that high activity leaves behind a large sample of archaeologically visible traces compared to low activity. SPDs can be biased by variation in sample size between sites, regions, or phases due to different circumstances, generating misleading peaks in the SPD. To control for overrepresentation from intensively dated sites, dates from each site were assigned to artificial bins, using a cut-off value of 100 years and running mean of 100 years (Shennan et al. 2013; Timpson et al. 2014; Crema and Bevan 2020). Monte Carlo simulations (n=1000) were used to test the significance of the SPD curve against a fitted exponential growth model of random dates (Shennan 2013; Timpson et al. 2014; Crema et al. 2016). I have chosen an exponential growth model as one, hypothetically, can expect increasing intensity in farming activity on a long-term scale, when it was first introduced to a region.

The SPD indicates a possible short phase of farming in the Early and Middle Neolithic before it disappeared for 500 years and reappeared in the Late Neolithic. This seems to back a hypothesis of a period without farming during the Neolithic (Hinsch 1955; Nielsen et al. 2019). Further, I aim to produce an age model that will provide high probability estimates for the start of arable farming in the different Neolithic phases of southeastern Norway. On this background, a Bayesian age model was built by including 44 samples dated to the Neolithic period attributed to two different phases separated by a hiatus of ca. 500 years: an Early/Middle Neolithic phase (2 dates) and a Late Neolithic phase (42 dates).

The model was built using the Bayesian statistical tools available in OxCal v4.3 according to the following structure in the OxCal Chronological Query Language 2: *Sequence*, *Boundary*, *Phase, Boundary*. (Bronk Ramsey 2009). Calibrated dates were produced using the IntCal20 calibration curve (Reimer et al. 2020). The model produces 68% and 95% posterior density estimates for the parameters defined by the model's structure. I have rounded the posterior density estimates to five years, as suggested by Bayliss (2015).

RESULTS

Summed Probability Distribution of Radiocarbon Dates

Figure 2 shows an SPD of all dated cereals without bins (Figure 2a), with bins (Figure 2b) and tested against an exponential growth model (Figure 2c). The radiocarbon dates are distributed from the transition to the Middle Neolithic to the early medieval period. The SPD is fluctuating and several interesting observations can be made. The absence of dated cereals before 5300 cal BP is noticeable. The lack of dated cereals in the Early Neolithic deviates from the development seen elsewhere in Scandinavia and will be addressed below. The first observation of dated cereals is between 5300 and 4800 cal BP, at the transition from the Early to the Middle Neolithic period. From 4900 to 4100 cal BP there is a negative deviation compared to the fitted growth model. The curve is again situated within the expected range of the growth model from 4100 cal BP, corresponding to the first part of the Late Neolithic. From this stage, there is continuous presence of direct evidence for arable farming in the region until modern times. There is however, a short-term negative deviation between 3250 and 3100 cal BP. From 2400 cal BP we observe the most noticeable feature in the SPD with a prominent boom and bust-cycle lasting until 1300 cal BP. The SPD displays a two-phased significant positive local deviation within this period, at 2400–1900 cal BP and 1700–1400 cal BP[1].

Bayesian Age Model

The model agreement index (A_{model}) is 84.7 and the individual agreement index ($A_{overall}$) is 78.5, thus above the recommended minimum acceptable value at 60% (Bayliss et al. 2007: 6). This indicates consistency between the data and the model (Bronk Ramsey 2009: 356–357).

The age model provides start dates for arable farming at the Early to Middle Neolithic transition and in the Late Neolithic (Figure 3). This corresponds to the first observations of

[1]To check if the boom and cycle between 2400 and 1300 cal BP is biased by the high number of dates from the Dilling-sites, I ran the same analysis excluding the dates from Dilling. The analysis shows the same pattern and is provided in the Supplementary Materials.

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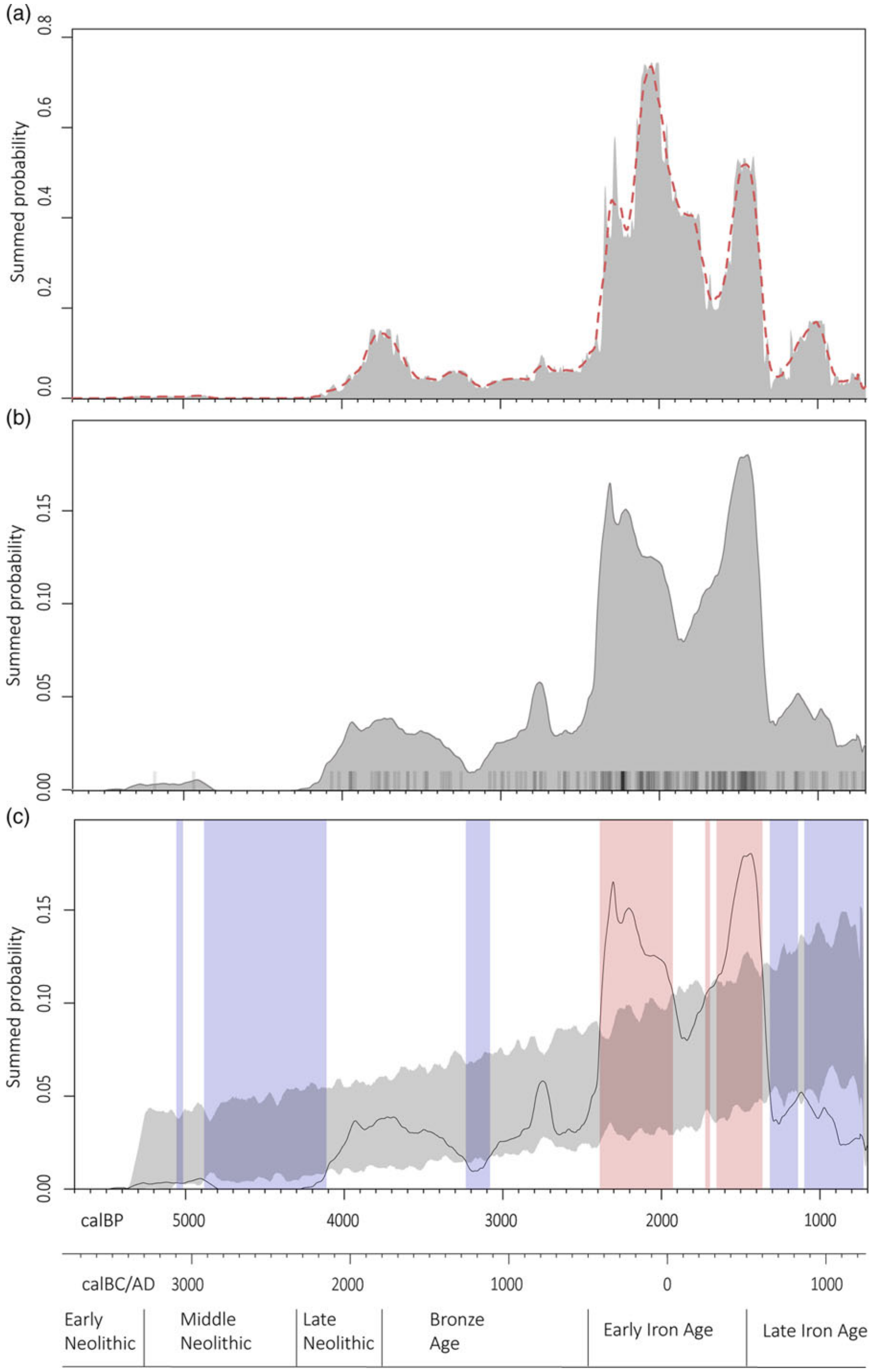

Figure 2 (a) Sum probability distribution of all dates without binning (n = 615). The dotted red line shows a running mean of 100 yrs. (b) The same dates structured in 100 years bins (n = 214) to control for overrepresentation of single sites with high numbers of dated cereals. (c) The SPD is tested against a fitted model of exponential growth (global p-value = 0.002). Significant positive local deviations (red): 1) 2389~1929 cal BP, 1725~1695 cal BP and 1653~1365 cal BP. Significant negative local deviations at (blue): 1) 5059~5018 cal BP, 4885~4114 cal BP, 3235~3082 cal BP, 1317~1140 cal BP, 1100~728 cal BP.

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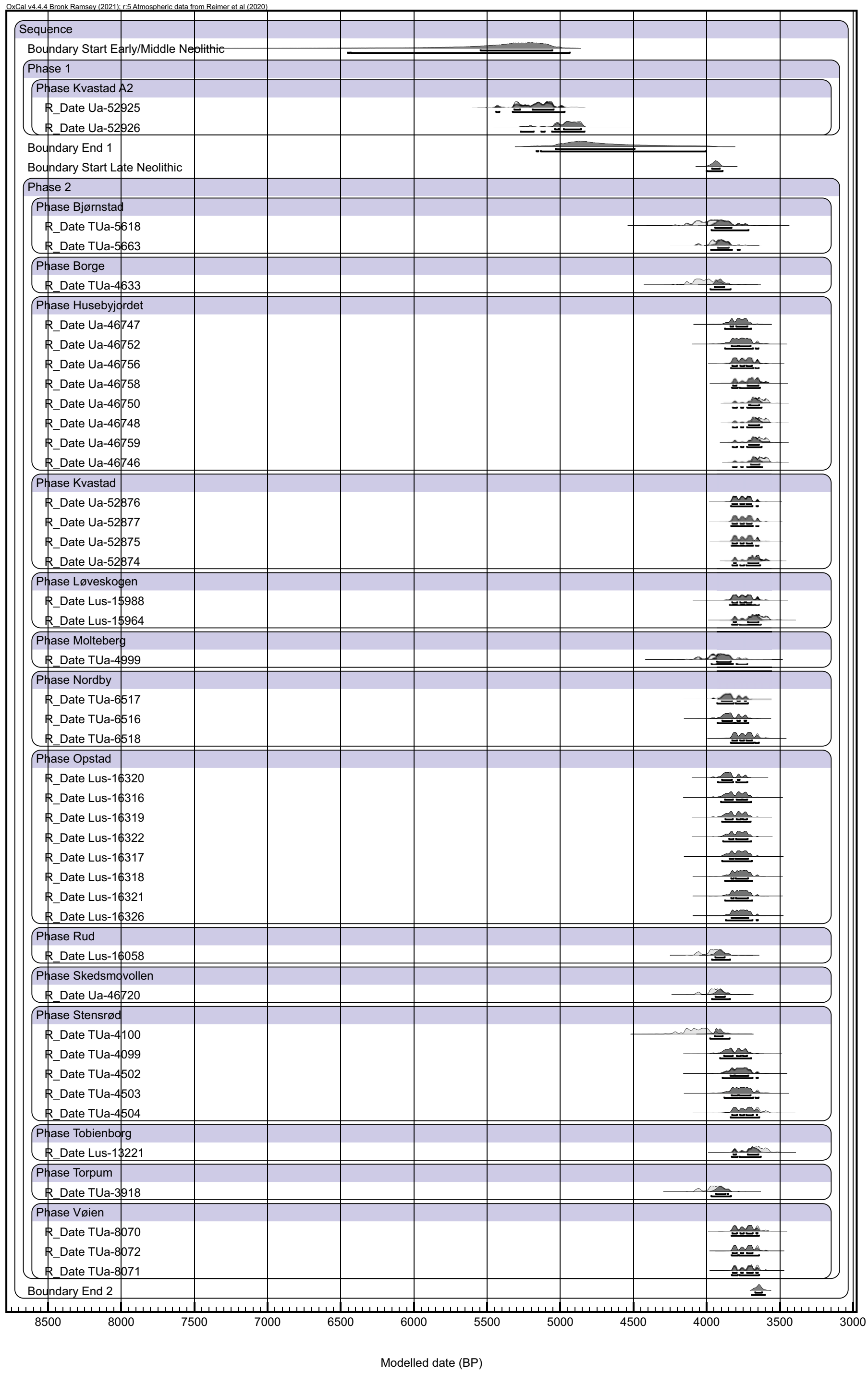

Figure 3 Age model multiplot showing the radiocarbon-dated cereals from the Neolithic period in southeastern Norway separated into an Early/Middle Neolithic and a Late Neolithic phase.

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charred cereals and, secondly, to the time from when cereals is continuously present in the region. The estimated start boundary for the Early to Middle Neolithic is between *6440 and 4920 cal BP (95%),* most probably between *5540 and 5050 cal BP (68%)*. The estimated end boundary is between *5165 and 4000 cal BP (95%)*, most probably between *5035 and 4490 cal BP (68%)*. It should be noted that for the early phase the estimates are relatively imprecise due to limited information caused by the low number of dates that can be attributed to the Early/Middle Neolithic phase. The estimated start Boundary for the Late Neolithic is between *4030 and 3890 cal BP (95%)*, most probably between *3985 and 3915 cal BP (68%)*, providing a more precise estimate of the start of Late Neolithic farming than the SPD.

DISCUSSION

Dating events and processes is central to archaeology, and timing the start of agriculture is a key topic in the study of prehistory. The methodological advancement in using large sets of radiocarbon dates to infer intensity in human activity provides a great potential to study relative variation in temporal development. Increased application of Bayesian analysis has improved the temporal control of events by integrating prior information in order to narrow down calibrated radiocarbon age distribution. Applying these techniques makes it possible to obtain a better insight into the process of establishing arable farming in southeastern Norway. The results presented above indicate that the establishment of farming was not a continuous process but rather a series of events taking place at different time stages and with different intensity. In the following, I will focus on three important time steps or periods, which also correspond with shifts in material culture, architecture and/or subsistence economy:

1) 6000–5000 cal BP: the period with the first indications of arable farming in southeastern Norway,
2) 4000–3900 cal BP: the start of continuous arable farming in southeastern Norway, and
3) 2400–2300 cal BP: a prominent increase and the final breakthrough of arable farming in southeastern Norway.

6000–5000 cal BP: Indications of Arable Farming in Southeastern Norway?

Arable farming spread rapidly across the Scandinavian Peninsula around 6000 cal BP, but compared to other parts of Scandinavia, the evidence for Early and Middle Neolithic arable farming is scarce and dubious in southeastern Norway. In southern Scandinavia cereals and bones from domesticated animals appear immediately after 6000 cal BP (Sjögren 2012; Sørensen and Karg 2014; Gron et al. 2016), and a shift in subsistence is further indicated by isotope analysis of human skeletal remains (Fischer et al. 2007; but see Jensen et al. 2019). In Middle Sweden farming is documented through dated cereals and domesticated animal bones from 6000–5900 cal BP (Hallgren 2012), while maritime hunter-gatherers at Åland in the northern Baltic, close to the environmental boundary of crop growing, adopted cereal cultivation at the same time (Vanhanen et al. 2019).

The above results show that evidence of arable farming first appeared in southeastern Norway between 5500 and 5000 cal BP, ca. 500 to 1000 years later than in the neighboring regions. The evidence is scarce and only two cereals from Kvastad A2 in Agder are dated to this period of time (cf. Figure 3). This limited evidence is difficult to interpret but can possibly indicate an early, short phase of farming or small scale gardening which left few traces of evidence (Sørensen 2014; Whitehouse and Kirleis 2014). The dates correspond with a charcoal peak in the sediment core from the nearby Låmyra bog, likely related to human activity at the site ca. 5000 cal BP (see below).

If we look closer at the site Kvastad 2, six dated cereals originate from two different contexts: a dug-down feature, possibly a hearth (A54643), containing 40 cereal grains of different types, and a poorly preserved cultivation layer (A53485) documented in patches across the site and in levels above hearth A54643, and containing one cereal grain. Five cereal grains from the dug-down feature were dated to between 5300–4800 cal BP and 3800–3600 cal BP (Table 2; Stokke and Reitan 2018: 404). The two early dates from Kvastad A2 are ca. 1000 years older than the other dated cereals from the Kvastad-site as well as the other samples in the dataset. Thus, one need to consider if these dates are erroneous dates and that the ^{14}C-measurment is incorrect. In retrospect this is hard to assess but the Tandem laboratory in Uppsala did not report any trouble with the dating procedure. The preservation conditions were generally poor at the site explaining the lack of organic material and the state of the cultivation layer. A likely explanation for the age difference in the radiocarbon dates from the hearth is that the structure originally dates to the Early/Middle Neolithic and later use of the site have disturbed the context mixing cereals from the Late Neolithic cultivation layer into the fill and contaminating the feature (Reitan et al. 2018). Accumulation of sediments above the hearth have provide relatively more favorable conditions for preservation of organic material compared to the cultivation layer and the rest of the site.

It is reasonable to assume that the earliest agriculture had a different form than later in the Neolithic (Gron et al. 2020). Thus, it is possible that arable farming was introduced to southeastern Norway through the Funnel beaker complex already at 5900 cal BP but that the archaeological traces are not preserved or visible today (Nielsen et al. 2019: 88). The lack of directly dated evidence for farming from the Early and Middle Neolithic is comparable to the low number of documented farming sites. Around 10 possible Early and Middle Neolithic farming sites located on easy arable sandy soils withdrawn from the coastal strip are known, with most of them documented either by finds of Neolithic pottery sherds or radiocarbon-dated anthropogenic features (see Reitan et al. 2018: 561–563 for an overview). Most likely, people inhabiting southeastern Norway knew farming and/or farming societies in neighboring regions during the first part of the Neolithic, as seen through finds of pottery and polished flint axes (Glørstad 2009; Glørstad and Solheim 2015). The prehistoric and historic core areas of farming in southeastern Norway, largely corresponding with the main distribution of Funnel beaker finds, are investigated intensively but sites from where soil samples and macrofossils are collected have not yet produced convincing evidence for arable farming dated to the Early and Middle Neolithic (Glørstad et al. 2020: 370). The only exception is Kvastad A2 but based only on the cereals from this site we cannot conclude that arable farming was practiced in the region. The available archaeological evidence does not show that subsistence nor settlement were altered to any substantial degree during the early parts of the Neolithic (Glørstad and Sundström 2014; Glørstad et al. 2020).

This development might be a parallel situation to what Bergsvik et al. (2020: 339–340) label as low-level agriculture among predominantly foraging groups. Low-level agriculture is hard to

Table 2 Selected palynological samples from bogs and lakes in southeastern and southernmost Norway with the earliest dated levels containing either cereal type pollen or ribwort plantain.

Sample ID	BP	SE	Context	Cereal type
Ua-52925	4551	56	Hearth, A54643	*Hordeum vulgare* var. *nudum*
Ua-52926	4351	55	Hearth, A54643	*Triticum dicoccum*
Ua-52876	3477	28	Hearth, A54643	*Avena* sp.
Ua-52877	3470	29	Hearth, A54643	*Avena* sp.
Ua-52875	3464	28	Hearth, A54643	*Hordeum vulgare* var. *nudum*
Ua-52874	3431	28	Cultivation layer, A53485	*Avena* sp.

identify and Hjelle et al. (2006: 163) argue that if we accept only directly dated macrofossils and bones of domesticated animals as evidence, there is a danger that we leave the early phases of the agricultural expansion unstudied. Due to the poor preservation of macrofossils in Neolithic contexts in southeastern Norway, this is an argument that deserves further investigation by looking at the indirect evidence of early farming from palynological samples.

Palynological Evidence for Early Farming

The identification of cereal-type pollen in sediment cores from lakes and bogs have been important in trying to identify early farming in southeastern Norway (Mikkelsen and Høeg 1979; Glørstad 2009). The presence of early farming based solely on these data can however be questioned because of the limited amounts of cereal pollen and the discrepancy between pollen data and other sources (Prescott 1996: 82–83). A problem with several of the sampled sediment cores is that the early finds of cereal pollen are often single finds of Hordeum-type. This is problematic as Hordeum can be mistaken for other species, such as wild grasses (Lahtinen and Rowley-Conwy 2013: 666). An important methodological issue in several of the performed analyses is that the precision in the dating of the layers containing cereal type pollen is low. The radiocarbon dates have large standard deviations and were often collected from bulk samples, and different levels in the sediment cores were dated by interpolation (Høeg et al. 2019: 104). The development in radiocarbon dating techniques has highly increased the precision in dating the layers in sediment cores and direct dating of several levels are now common (e.g., Wieckowska-Lüth et al. 2017).

Cereals such as wheat and barley are self-pollinating species, meaning that the pollen does not spread over long distances. For several sampled pollen sites with cereal pollen, it is a challenge to establish a link between the pollen sites' catchment area and archaeologically documented human activity. A palynological investigation that exemplifies this is the analysis of a sediment core from the Låmyra bog, less than 100 m from the above-mentioned archaeological site Kvastad A2 (Reitan et al. 2018: 554–555). No farming indicators, such as cereal-type pollen or ribwort plantain are identified in the sediment core in levels dated to ca. 5000 cal BP. Two peaks in the amount of microscopic charcoal and an increase in the frequency of grass (*Poaceae*), possibly resulting from anthropogenic activity such as small-scale clearing of land, correspond in time with the dated cereals from the archaeological context. Hence, the absence of farming indicators in the sediment core does not necessarily exclude the possibility of crop growing taking place nearby but neither does it confirm it. It is possible that the dated cereals represent local cultivation but it does not rule out the possibility that

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the cereals were brought into the archaeological site. The discrepancy between the archaeological and palynological data from Kvastad A2 and the nearby Låmyra bog, highlight the challenges of using pollen analysis to determine the presence of early arable farming in the region (Reitan et al. 2018: 556).

Still, the accumulated evidence of palynological data from sediment cores give hints on Early and Middle Neolithic farming (Table 3, see also Høeg et al. 2019). In Wieckowska-Lüth and colleagues' (2017) detailed study of long-term vegetation development based on a sediment core from Lake Skogstjern, Telemark, the first farming indicators occurs 5500–5400 cal BP, consisting of a single cereal pollen grain of Hordeum-type together with ribwort plantain, a taxon characteristic of open grazed as well as fallow land. At these levels, Wieckowska-Lüth et al. documented pollen from grasses, ruderal herbs and traces of spores of decomposing fungi, which thrive on animal dung. The evidence of agriculture is sporadic after this stage and cereal type pollen is not identified until ca. 5000 cal BP and then occasionally until 1800 cal BP. The presence of ribwort plantain is regular but scattered in levels younger than 5700–5500 cal BP. A continuous presence of both cereal-type pollen and ribwort plantain is documented from 1900–1800 cal BP (Wieckowska-Lüth et al. 2017: 6, 11).

In other selected palynological records (Table 3), the first traces of ribwort plantain and cereal-type pollen are identified at levels dated to 3600–3500 cal BP and 2200–2000 cal BP respectively in Møllermosen, Østfold (Høeg 2002: 125, 135). Palynological investigations of several lakes and bogs at Romerike, Akershus, display an earliest presence of a single pollen of ribwort plantain from 5750–5300 cal BP and a single Hordeum type pollen from levels dated to 3870–3635 cal BP in Danielsetermyr (Høeg, 1997: 31–32, 129–130). Early observations of ribwort plantain comes from Tjønnemyr and Ringdal, Vestfold, dated to 7430–7170 cal BP and 7420–6220 cal BP while ribwort plantain and Hordeum-type pollen is found in Napperødtjern, Vestfold, at levels dated to 7280–6640 cal BP and 7265–6675 cal BP respectively (Henningsmoen 1980). These dates are problematic as they date the presence of farming indicators to final phase of the Mesolithic where there are no evidence for the presence of farming in this or neighboring regions (e.g., Sørensen and Karg 2014; Bergsvik et al. 2020).

At Lista, the southernmost tip of Norway, indications of arable and pastoral farming display synchronicity. In Lake Braastadvatn and Lake Kviljotjønn pollen from cereals and ribwort plantain appear shortly after the isolation of the basin, dated to 6640–6310 cal BP (5685 ± 65 BP, TUa-665A) and 6190–5900 cal BP (5240 ± 60 BP, TUa-719A), respectively (Prøsch-Danielsen 1996; Prøsch-Danielsen 1997). This can be traces of low-level agriculture during the Early Neolithic, but the dates are controversial, as they possibly reflect the presence of sand-dune vegetation (Prøsch-Danielsen 1996: 95).

The finds of early cereal pollen and ribwort plantain from lakes and bogs throughout southeastern Norway must be treated with caution as evidence for farming. The accumulated palynological evidence shows that ribwort plantain appears from between 6000 and 5000 cal BP and cereal pollen after 5000 cal BP. Frequent farming indicators and continuous presence of ribwort plantain and cereal are first identified at a later stage (Prøsch-Danielsen 1996: 96; Wieckowska-Lüth et al. 2017). Present evidence is equivocal and any conclusions based on pollen analysis need support by finds of charred cereals and/or domesticated animal bones to conclude on the presence of farming. So far, only one bone of Bos domesticus is dated to the Middle Neolithic period in southern Norway, from

Table 3 Radiocarbon dated cereal grains from Kvastad A2.

Palynological samples		Plantago lanceolata			Cerealia		Hordeum				
Site	Location	Dated layer	Calibrated date	Date interpolated	Dated layer	Calibrated date	Dated layer	Calibrated date	Date interpolated	Comment	Reference
Danielsetermyr	Akershus	4835 ± 80 BP (lab. ref NA)	5740–5320 cal BP				3480 ± 45 BP (lab. ref NA)	3870–3630 cal BP			Høeg 1997
Bånntjern	Akershus			4300 cal BP			3975 ± 100 BP (lab. ref NA)	4820–4150 cal BP			Høeg 1997
Svenskestutjern	Akershus	4415 ± 105 BP (lab. ref NA)	5540–4820 cal BP						2500 cal BP		Høeg 1997
Sagavoll	Telemark	4680 ± 60 BP (T-2123)	5590–5300 cal BP						2200 cal BP		Høeg 1989
Solbergtjern	Telemark	4390 ± 60 BP (T-2121)	5280–4840 cal BP						3900 cal BP		Høeg 1989
Skogstjern	Telemark								5500 cal BP	Single pollen	Wieckowska-Lüth et al. 2017
Barlindtjern	Aust-Agder	4630 ± 100 BP (lab. ref NA)									Høeg 1982
Skjoldnesmyr 1	Vest-Agder			5550 cal BP	3960 ± 110 BP (T10496a)	4420 cal BP			5400 cal BP		Høeg 1995
Fjellestadmyr 1	Vest-Agder			3350 cal BP					3350 cal BP		Høeg 1995
Fjellestadmyr 2	Vest-Agder			4200 cal BP*					2000 cal BP		Høeg 1995
Jølletjønn	Vest-Agder	4790 ± 80 BP (Beta-59438)	5660–5315 cal BP	5500 cal BP	3940 ± 130 BP	4390 cal BP			4100 cal BP		Høeg 1995
Hallandsvann	Vest-Agder	5010 ± 70 BP (Tua-932a)	5910–5610 cal BP		5010 ± 70 BP (Tua-932a)	5910–5610 cal BP				Single pollen	Prøsch-Danielsen 1996
Kviljotjønn	Vest-Agder	5240 ± 60 BP (Tua-719a)	6190–5900 cal BP		5240 ± 60 (Tua-719a)	6190–5900 cal BP				Single pollen	Prøsch-Danielsen 1997
	Vest-Agder				3800 ± 60 BP (Tua-933a)	4410–3990 cal BP					
Braastadvann	Vest-Agder	5685 ± 65 BP (TUa-665a)	6640–6310 cal BP		5685 ± 65 (TUa-665a)	6640–6310 cal BP				Single pollen	Prøsch-Danielsen 1997
Hanangervann	Vest-Agder			8300 cal BP	3840 ± 85 (TUa-1037a)	4510–3980 cal BP					Prøsch-Danielsen 1997
Ersdal myr, Flekkefjord	Vest-Agder			4550–4300 cal BP							Høeg 1999
Ersdal fiskelausvann	Vest-Agder	4910 ± 90 BP (lab. ref NA)									Høeg 1999

(Continued)

Table 3 (*Continued*)

Palynological samples		Plantago lanceolata			Cerealia		Hordeum				
Site	Location	Dated layer	Calibrated date	Date interpolated	Dated layer	Calibrated date	Dated layer	Calibrated date	Date interpolated	Comment	Reference
Napperødtjern	Vestfold				6095 ± 135 BP (lab.ref NA)	7280–6640 cal BP	6105 ± 120 BP (lab.ref NA)	7265–6675 cal BP			Henningsmoen 1980
Tjønnemyr, Sandefjord	Vestfold	6390 ± 60 BP (lab. ref NA)	7430–7170 cal BP							Mesolithic date	Høeg unpubl.
Ringdal, Sandefjord	Vestfold	5915 ± 260 BP (lab. ref NA)	7420–6220 cal BP							Mesolithic date	Høeg unpubl.
Haraldstadmyra	Østfold	5010 ± 100 BP (lab. ref NA)	5990–5580 cal BP							Not insepcted	Not published
Møllermosen	Østfold	3760 ± 85 BP (T-15758)	4410–3910 cal BP						2100 cal BP		Høeg 2002

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Stangelandshelleren in Rogaland, southwestern Norway (4405 ± 65 BP, 5285–4850 cal BP; Høgestøl and Prøsch-Danielsen 2006).

In conclusion, the available archaeobotanical and palynological data suggest that arable farming was, at best, limited during the Early and Middle Neolithic.

4100–3900 cal BP: the Start of Continuous Arable Farming in Southeastern Norway

The SPD shows a continuous presence of dated cereals grains from ca. 4100 cal BP. The Bayesian age model provides a more detailed picture of the start of Late Neolithic farming with an estimated boundary start at *4000–3890 cal BP (95%)*, or most likely between *3965–3910 cal BP (68%)*. This is later than the start of the Late Neolithic chronological period at 4400–4300 cal BP, and suggest a later start of arable farming than previously suggested. From this date, there is unambiguous evidence for the presence of an agrarian economy and arable farming in southern Norway. The pattern identified by radiocarbon-dated cereals in this study finds support in radiocarbon dates from tilled layers and clearance cairns demarcating the start of more regular tilling and cultivation of soils in the region from ca. 4000 cal BP (Mjærum 2020). Only a few tilled layers date earlier than 4000 cal BP but Mjærum interpret these dates as contextually flawed and not related to farming and tillage (Mjærum 2020: 11).

From ca. 4000 cal BP there was radical shift in the subsistence base and settlement pattern with specialized modes of agro-pastoral economy and production being present in southern Norway from this time stage. Arable farming and cereal cultivation is documented in products such as cereals, as well as through practice including tilling, and harvesting tools such as sickles (Rønne 2003; Mjærum 2020). Bones, teeth and coprolites dated to between 4500 and 4000 cal BP document the presence of domesticated animals (Figure 4). The establishment of an agro-pastoral economy represents a significant societal shift reflected in material culture, architecture and settlement patterns, and traits associated with traditional farming settlement, such as two-aisled long houses and tilled fields, are now present. A similar trajectory took place in southwestern Norway as well (Prøsch-Danielsen et al. 2018). The emergence and spread of farming into different ecological niches indicates a flexible and mixed economy during the Late Neolithic and Bronze Age, based on crop growing, animal husbandry and the use of wild resources. Remains of domesticated animals from upland areas and in the large river valleys demonstrate transhumance and use of summer pastures in upland areas (Prescott 2012; Melheim and Prescott 2016). In addition to the osteological and archaeobotanical evidence palynological analysis from different ecological niches in southern Norway display the presence of indirect farming indicators (Hjelle et al. 2006). Based on this it is suggested that the structure of the historical farm was established in southern Norway through a gradual process most likely caused by interaction with Bell beaker groups (Prescott 2020: 38). The shift in economic strategies identified around 4000 cal BP is consistent with an upswing in population in the region further illustrating the expansion of farming (Nielsen et al. 2019; Solheim 2020; Bergsvik et al. 2021).

2500–2400 cal BP: a Prominent Increase and the Final Breakthrough of Arable Farming in Southeastern Norway

The third stage emphasized here starts at the transition to the Early Iron Age, ca. 2500–2400 cal BP. The SPD displays a prominent boom and bust-cycle with two positive deviations between

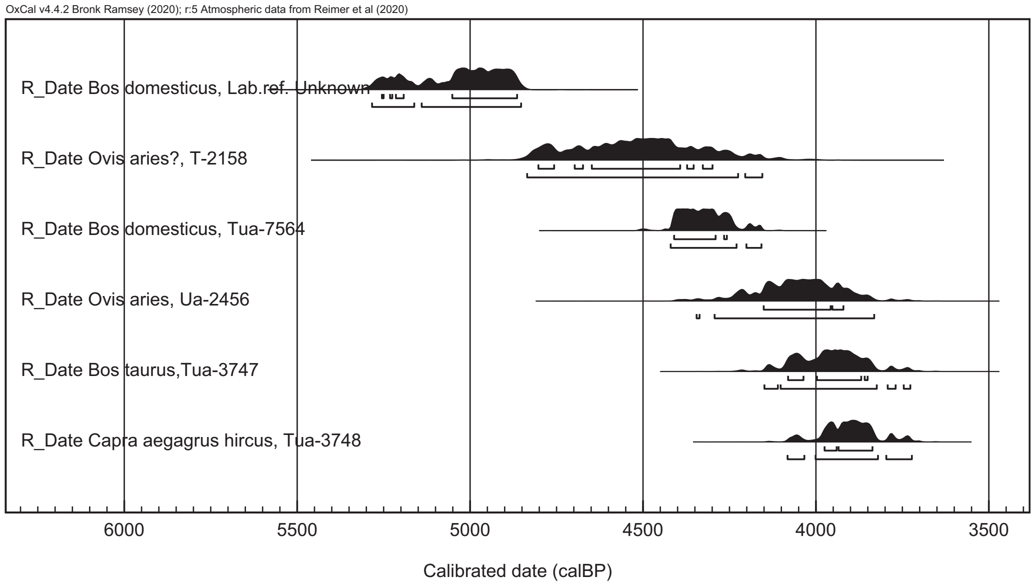

Figure 4 Calibrated radiocarbon dates of bone, teeth, and coprolite from domesticated animals. T-2158 is tentatively determined as sheep. Only the ox tooth from Stangelandshelleren predate the Late Neolithic period. Unfortunately, the dating report is not published, explaining the lack of laboratory reference. The dates are from western and central parts of Norway, hence outside the study area.

ca. 2400 and 1900 cal BP, and 1730 and 1400 cal BP. Between 1400 and 1300 cal BP the probability curve drops outside the confidence interval.

From the Early Iron Age there is, in addition to charred cereals at archaeological sites, a continuous presence of cereal pollen in pollen diagrams throughout southeastern Norway (Høeg 1997; Svensson and Regnell 2013; Wieckowska-Lüth et al. 2017). Available data demonstrate intensified and mixed farming including manuring with animal dung on permanent fields (Bårdseth and Sandvik 2010; Mjærum 2020) coinciding with a shift in the practice of crop growing to hulled barley which is more susceptible to manuring (Lillehammer 2016: 167). Population models suggest that the period ca. 4000–2000 cal BP was a period of growing population sizes (Solheim and Iversen 2019: 429; Solheim and Persson 2018: 338). An increasingly intensive mixed farming economy led to utilization of larger parts of the region's landscape and clearing of land during the Early Iron Age (Gjerpe 2013). Stone-rich moraine deposits were transformed into arable land, possibly as late as 2400 cal BP, as a supplement to already cultivated areas demonstrating an expansion in farming (Mjærum 2020). These soils were well suited for arable farming, as long as the necessary resources were invested in clearance and fertilization. Mjærum (2020: 17) suggest that the transformation in the use of the landscape started during the last part of the Bronze Age. This finds support in the increasing amount of dated cereals from ca. 3000 cal BP building up to a major breakthrough at 2400 cal BP, when an integration of stockbreeding and cultivation became vital parts of a system that provided the necessary resource basis for the emergence of Iron Age societies.

CONCLUSION

In this paper, I have used radiocarbon-dated charred cereal grains to address the emergence of arable farming in southeastern and southernmost Norway. By modeling radiocarbon dates in an SPD using *Rcarbon* and in a Bayesian age model produced in OxCal, I have pointed out three different stages as pivotal in this the long-term development: the first period discussed was the time between 6000 and 5000 cal BP when the first evidence indicating arable farming occur in the archaeological record. While these early dated cereals could be remains of small-scale gardening or low-level agriculture they cannot provide solid evidence of arable farming except for the presence of cereals. The Bayesian age model provide an a relatively imprecise estimated start boundary for occurrence of arable farming between 6455 and 4935 cal BP (95%), most probably between 5545 and 5050 cal BP (68%). Secondly, the SPD showed the emergence of arable farming with a continuous presence of cereals from ca. 4000. The Bayesian age model estimated the start of Late Neolithic farming to date between *4000 and 3890 cal BP (95%)*, or most likely between *3965 and 3910 cal BP (68%)*. The age model showed that the establishment of arable farming based on the presence of cereals occurred ca. 200–300 years later than previously argued (Prøsch-Danielsen et al. 2018; Prescott 2020). This demonstrates the value of statistically testing radiocarbon data to provide accurate estimates for archaeological processes and events. Finally, the SPD demonstrated that the final breakthrough and expansion of agriculture took place from ca. 2400 cal BP, during the Early Iron Age.

I have considered the remains of cultivated plants such as cereals as the most reliable source for tracing early arable farming (Behre 2007: 203). Methodological advancement, including dating techniques, has provided significant new information on the development in landscape use in southeastern Norway and elsewhere (e.g., Wieckowska-Lüth et al. 2018, 2017) and pollen analysis from sediments from lakes and bogs provide an important tool for identifying human impact on the landscape including prehistoric farming. Palynologists have identified single or sporadic pollen grains of cereal pollen and ribwort plantain in sediments cores from lakes and bogs but interpreting early arable farming based only on the palynological evidence so far put forward in the study area is questionable.

This paper is the first to include all available directly dated evidence for arable farming in southeastern Norway. The results presented here demonstrate that the introduction of arable farming to southeastern Norway was not a simple evolutionary process where farming became increasingly important. Rather it was a long-term development including several steps. There is a discrepancy of ca. 500–1000 years in the timing of the first evidence of arable farming seen in the data from southeastern Norway compared to other parts of Scandinavia. The accumulated evidence of radiocarbon dates put forward here strongly suggest that arable farming was established in the Late Neolithic period before its final breakthrough in the Early Iron Age. This study further illustrates the complexity and variety in temporal and regional developments in the introduction of farming across Europe.

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Dilling—A Pre-Roman Iron Age Village? in 2021. This paper is part of the Past Global Changes (PAGES) PalEOclimate and the Peopling of the Earth (PEOPLE3 K) network. Data and software code can be found here: https://doi.org/10.5281/zenodo.5502654.

SUPPLEMENTARY MATERIAL

To view supplementary material for this article, please visit https://doi.org/10.1017/RDC.2021.80

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