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**Possible wild boar management during the Ertebølle Period. A carbon and
nitrogen isotope analysis of Mesolithic wild boar from Fannerup F,
Denmark**

Abstract

This paper presents a stable isotope and radiocarbon study on a total of 85 samples of wild boar (*Sus scrofa*), humans (*Homo sapiens*), dogs (*Canis familiaris*), red deer (*Cervus elaphus*) and roe deer (*Capreolus capreolus*) from four Late Mesolithic sites in Jutland, Denmark. Four of the eight *Sus scrofa* samples from one site, the shell midden of Fannerup F, show markedly enriched carbon and nitrogen isotope values, indicating a dietary intake of a substantial amount of marine food. In contrast to standard interpretations of Late Mesolithic animal economy, we suggest that the enriched values of *Sus scrofa* may be an indication of management by Ertebølle groups in the area that facilitated access to substantial amounts of marine foods for these wild boars compared to contemporaneous conspecifics. The ^{14}C dates of the *Sus scrofa* range from 5290-4335 cal BC, suggesting that the management of *Sus scrofa* developed independently of contact with Neolithic societies. Although the sample size remains small, the interpretation of Late Mesolithic animal management adds to the growing evidence for political and economic complexity in the Ertebølle culture.

Keywords *Sus scrofa*; domestication; stable isotope analysis; Ertebølle culture; niche construction

Highlights:

- 85 stable isotope values of red deer, roe deer, wild boar, dogs and humans from the Danish Ertebølle culture
- 21 radiocarbon dates were obtained on bone collagen from four different sites
- Stable isotope values show that four *Sus scrofa* had consumed marine fish akin to contemporaneous *Canis familiaris*
- Evidence for possible management of *Sus scrofa* by Mesolithic foragers

1. Introduction

A decade of intense research into the prehistoric domestication processes has led to a general consensus that the domestication of *Sus scrofa* – the wild boar – happened in several geographic regions and at different times (Albarella et al. 2007, Anderson 2007, Larson et al. 2005, Larson et al. 2007). Despite occurring relatively late, the domestication of the pig has been argued to be comparable to that of the dog: The two animals have several similarities such as intelligence and behavioural flexibility. Importantly, pigs are omnivores, and commonly feed on the leftovers of human food (Albarella et al. 2007). The wild boar has been an important meat resource for humans long before domestication took place. Domestication altered the relationship between wild boar and humans (Albarella et al. 2007, Larson et al. 2007, Rowley-Conwy & Dobney 2007) with humans bringing the pig outside its natural range (Larson et al. 2007).

After a brief presence of *Sus scrofa* in the warmer parts of the Late Glacial, the wild boar has been part of the endemic fauna of southern Scandinavia since the Preboreal (Aaris-Sørensen, 2009). The current consensus is that multiple centres of domestication existed across Eurasia (Larsen et al. 2005,) and subsequently the European domestic pigs were introduced to northern Germany and southern Scandinavia (Rowley-Conwy & Dobney 2007). In Denmark, specifically, the introduction is set at around 4000-3900 BC, corresponding to the introduction of the rest of the 'Neolithic package' (Fischer 2002).

In contrast, some have claimed that the arrival of the domesticated pig happened earlier.

Based on geometric morphometrics, nDNA and mtDNA, Krause-Kyora and colleagues (2013)

claim that three pigs from the north German site Grube-Rosenhof (sample: E24, E44) and Pole (sample: E69), which possessed the Near Eastern haplotype Y1, were domestic pigs (Krause-Kyora et al. 2013, Evin et al. 2014a). If correct, this would predate the presence of domesticated pigs in the area by about 500 years compared to previous estimates. This claim, in turn, has been questioned by Rowley-Conwy & Zeder (2014a & 2014b) who, based on metric evidence, conclude that the animals analysed by Krause-Kyora et al. (2013) were most probably wild boar with some domestic ancestry rather than fully domesticated pigs. Demonstrating that some Ertebølle wild boar have domestic ancestry is, however, not equivalent to concluding that these animals were either behaviourally domestic or kept by the Ertebølle people for consumption as domestic animals (Rowley-Conwy & Zeder 2014a). New mtDNA studies indicate that the Neolithic farmers (5000-4000 BC) only brought a relatively small number of female domestic pigs to northern Europe. A high level of interbreeding with the local wild boar indicate a loose management system of the domestic pigs; a management that relied on interaction with wild boars (Caliebe et al. 2017). Thus, the questions of when the management and domestication of *Sus* commenced in southern Scandinavia remains unresolved at present.

Finds of 'pig' bones from periods earlier than the Neolithic in Denmark have always been assumed to be wild boar, despite being morphologically almost impossible to distinguish from early domestic pigs (Rosvold et al. 2010, Rowley-Conwy et al. 2012). The challenge of distinguishing between the two has been addressed through the application of various methods (Rosvold et al. 2010, Rowley-Conwy et al. 2012, Evin et al. 2013, Evin et al. 2014b), one of which is stable isotope analysis. The expectation that the stable isotopic signatures of domesticated and wild pigs differ derives from the hypothesis that domesticated pigs would

have had access to other food sources compared to wild boar, and thereby should be distinguishable using carbon and nitrogen isotope analysis (Rosvold et al. 2010). Framed differently, we expect that pig fodder would be under some control by their keepers (Rowley-Conwy et al. 2012). In debating whether Ertebølle groups in northern Europe were keeping domesticated pigs before the arrival of farming, Rowley-Conwy et al. (2012: 37) state that ‘it can be argued that isotopes are the most revealing of these approaches: if the pigs had been kept on the settlement of maritime hunter-gatherers, their diet should have included marine waste...’.

This paper reports stable isotope analyses of a selected sample of *Sus scrofa* bones from the Danish shell-midden ‘Fannerup’ located in the eastern part of Central Jutland (Fig. 1). By comparing carbon and nitrogen isotope values of the *Sus scrofa* samples to those of other sites and of other animals, including undoubtedly domesticated dogs fed on marine waste, we aim to improve our understanding of the relation of *Sus scrofa* to contemporaneous Ertebølle foragers.

The *Sus scrofa* bones were sampled as part of a larger study of the variability of carbon and nitrogen isotope values of the major terrestrial sources of meat during the Ertebølle period for clarifying whether their isotope values would reflect subtle environmental differences rather than dietary choices (cf. Bonafini et al. 2013). Surprising results of the *Sus scrofa* from Fannerup F emerged and changed the focus of our investigation. We also present stable isotope analyses of selected samples of red deer (*Cervus elaphus*), roe deer (*Capreolus capreolus*), wild boar (*Sus scrofa*), dogs (*Canis familiaris*) and humans (*Homo sapiens*) from Fannerup F, as well as from three other Danish sites: Nederst, Yderhede and Østenkær. The

carbon and nitrogen isotope values of these animals form a baseline for comparison and for reconstructing the diet of *Sus scrofa*.

Figure 1. The location of the sites in present-day Denmark.

2. Materials and methods

Stable isotope analyses provide us with a technique for investigating the diets of prehistoric humans and animals, which is independent of artefactual evidence. Carbon ($^{13}\text{C}/^{12}\text{C}$) and nitrogen ($^{15}\text{N}/^{14}\text{N}$) stable isotope ratios (expressed respectively as $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$) in bone collagen are particularly useful in studies of diet composition, enabling discrimination between terrestrial, freshwater and marine food intake (van der Merwe 1982, Schoeninger et al. 1983, Price et al. 1985, DeNiro 1987, Tauber 1989, Ambrose & Norr 1993, Eerkens et al. 2013, Mannino et al. 2015). The bone collagen component, however, primarily reflects the

protein intake of the diet, especially in diets rich in animal protein. This implies that food resources with low protein content are hardly detectable through stable isotope analyses of bone collagen (Schoeninger & Moore 1992, Ambrose & Norr 1993, Hedges et al. 2004). $\delta^{13}\text{C}$ values of animals and humans will closely resemble the values of their diet, but will often be slightly enriched, while $\delta^{15}\text{N}$ values of humans or animals are enriched by 3-5 ‰ compared to the diet (Schoeninger et al. 1983, Schoeninger & DeNiro 1984, DeNiro 1987, Ambrose & Norr 1993, White et al. 2001, Bocherens & Drucker 2003, Hedges & Reynard 2007).

As with humans, pigs are omnivores and inevitably consume a wide variety of food items, resulting in isotope values which are potentially very complicated to interpret (Madwick et al. 2012, Rowley-Conwy 2013).

In Mesolithic Denmark, C_4 plants (corn, millet and tropical grasses) were absent, meaning that the carbon isotope ratio is primarily useful to distinguish between the consumption of marine and terrestrial food sources (Tauber 1989, Fischer et al. 2007a, Olsen et al. 2008). The established interpretation of stable isotope values of humans from the Danish Ertebølle culture indicate a high intake of marine components, represented by $\delta^{13}\text{C}$ values between -16 ‰ and -10 ‰. People with a $\delta^{13}\text{C}$ value around -10 ‰ have mainly fed on food from the sea, where an intake around 50 % marine foods will result in a $\delta^{13}\text{C}$ value of around -16 ‰ (Fischer 2005, Olsen et al. 2008). The assumptions concerning which diets correspond to which carbon and nitrogen values are based on generalised baselines. Furthermore, the $\delta^{15}\text{N}$ values (12-16 ‰) indicate that the diet belongs to the higher end of the food chain and probably included marine mammals such as seals (Olsen et al. 2008).

2.1 Fannerup F, Nederst, Yderhede & Østenkær

Bones were sampled from the shell-midden Fannerup F (DJM 2233), in eastern Central Denmark (see Fig. 1). The site is located in an area where ten other shell-middens dating to either the Mesolithic or the Neolithic are known. Fannerup F was excavated by Djursland Museum (now part of Museum Østjylland) between 1987-1988 and consists of a compact shell layer with a large number of bones, flint tools and waste, as well as two human inhumations (Rasmussen 1990). The shell-midden has been radiocarbon dated to 5255-4175 cal BC, while the two burials date to the much narrower time interval of 4940-4725 cal BC. Eight different wild boars, one roe deer, five red deer and two humans were sampled from Fannerup F.

In order to derive an isotopic baseline for the dietary interpretations of Fannerup F, additional bones were sampled from the site Nederst (DJM 2123). Nederst consists of three shell middens located in fairly close proximity to Fannerup F, but on the opposite side of the Kolindsund fjord. The excavations of the shell middens at Nederst were conducted by Djursland Museum in 1988-1991 and revealed six human inhumations between two of the shell middens, several fragments of other humans and four buried dogs along with other skeletal remains of dogs (Kannegaard 2016). Similarly, to Fannerup F, ¹⁴C dating attributes the Nederst shell midden to 5225-4040 cal BC, with the only dated dog falling into the latest stages of this time interval (4230-4040 cal BC). Bones from three wild boars, five roe deer and three dogs were selected for sampling.

The two sites of Yderhede (VHM190/1987) and Østenkær (VHM90/1968) are both located on the northern tip of the Jutland peninsula and exhibit almost identical excavation histories and

discovery circumstances. Both sites were previously recorded by Vendsyssel Historiske Museum when landowners decided to dig duck ponds. This activity exposed Ertebølle culture refuse layers, including large amounts of animal bones and flint tools. Yderhede is the oldest site of the two, with ^{14}C dates placing its occupation around 5525-4850 BC (Enghoff 2011). Østenkær has been radiocarbon dated to 5210-3670 BC (Enghoff 2011). The bones sampled from Yderhede include: four roe deer, two wild boars and eleven red deer specimens. Those from Østenkær comprise: one dog, ten wild boars, ten roe deer and twenty red deer specimens. A total of 21 samples were also radiocarbon dated (Fig. 2 and Table 1).

Figure 2. *The calibrated probability distributions of the ^{14}C dates on the human and animal remains from the four sites. The graph is generated with OxCal 4.24 (Ramsey 2009) using the terrestrial calibration curve IntCal13 (Reimer et al. 2013). The radiocarbon dates of humans and animals are not corrected for the reservoir effect unless a minimum intake of 10 % marine food is observed. Thus, a $\delta^{13}\text{C}$ value of -21 ‰ or lower will result in no correction, while a $\delta^{13}\text{C}$ value of -10 ‰ or more, implying 100% marine diet, involves a correction of minus 400 years (Heinemeier et al. 1993, Heier-Nielsen et al. 1995).*

Collagen was extracted using a modified Longin-procedure with ultrafiltration (Longin 1971, Brown et al. 1988, Jørkov et al. 2007). An acid solution of 1M HCL was added to the cleaned and drilled bone samples to dissolve the mineral component at 5 °C until the reaction was completed, and no further CO_2 was released. The samples were subsequently rinsed twice with Milli-Q water to neutrality and 0.2 M NaOH was added for 15 minutes at room temperature. Finally, the samples were rinsed twice with Milli-Q water and 0.01M HCL was added to dissolve the collagen at pH 2, at 58 °C for 48 hours. The samples were filtered through 5-8 μm Ezeefilters, ultra-filtered and the >30kDa fraction freeze dried.

Collagen was generally well-preserved and all samples had extraction yields between 0.43 and 11.58%. The C:N ratios were within the accepted range of 2.9 to 3.6 (DeNiro 1985, van Klinken 1999). Between 1.09 and 61.6 mg of bone collagen was extracted from each sample (Table 1). The samples were measured on an IsoPrime Ratio Mass Spectrometer coupled with a Vario Cube Elemental Analyser at Aarhus AMS Centre (AARAMS), Aarhus University with a precision of $\pm 0,3$ ‰ $\delta^{13}\text{C}$ and $\pm 0,5$ ‰ $\delta^{15}\text{N}$. International standards USGS 40 (glutamic acid $\delta^{13}\text{C} = -26.39$ ‰, $\delta^{15}\text{N} = -4.52$ ‰), USGS 41 (glutamic acid $\delta^{13}\text{C} = 37.63$ ‰, $\delta^{15}\text{N} = 47.6$ ‰)

and in-house standards of bone collagen and commercial gelatin. Every fifth sample and all of the wild boar bones from Fannerup F were measured twice.

Table 1. *Isotopic values, C:N ratios and radiocarbon dates undertaken as part of the research for this study. The ^{14}C dates are reported after Stuive & Polach (1977).*

Sample no.	Site	Species	Lab no.	BP	Res-corr BP	BC (2 σ)	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	C:N ratio	% yield
21802	Fannerup F	<i>Homo sapiens</i>	AAR-19687	6377 $\pm$ 30	6006 $\pm$ 30	4940-4845	-10.8	14.3	3.2	4.72
21803	Fannerup F	<i>Homo sapiens</i>	AAR-19688	6274 $\pm$ 31	5921 $\pm$ 31	4840-4725	-11.3	17.0	3.2	3.22
21804	Fannerup F	<i>Capreolus capreolus</i>	AAR-19689	5378 $\pm$ 31		4325-4175	-21.7	6.4	3.2	3.46
21805	Fannerup F	<i>Cervus elaphus</i>					-20.1	4.3	3.2	1.47
21806	Fannerup F	<i>Cervus elaphus</i>					-21.3	4.4	3.3	1.12
21807	Fannerup F	<i>Cervus elaphus</i>					-20.8	4.5	3.2	1.56
21808	Fannerup F	<i>Cervus elaphus</i>					-20.0	4.3	3.2	0.50
21810	Fannerup F	<i>Sus scrofa</i>					-20.9	7.0	3.2	1.30
21811	Fannerup F	<i>Sus scrofa</i>	AAR-22452	6471 $\pm$ 33	6221 $\pm$ 33	5290-5075	-14.0	11.1	3.2	1.44
21812	Fannerup F	<i>Sus scrofa</i>	AAR-19690	6549 $\pm$ 32	6214 $\pm$ 32	5285-5070	-11.7	12.6	3.2	2.03
21813	Fannerup F	<i>Sus scrofa</i>	AAR-19691	6345 $\pm$ 37	6138 $\pm$ 37	5210-5000	-15.3	10.9	3.2	3.07
21838	Fannerup F	<i>Sus scrofa</i>					-19.2	5.3	3.2	1.44
21839	Fannerup F	<i>Cervus elaphus</i>					-20.4	4.9	3.2	1.58
21840	Fannerup F	<i>Sus scrofa</i>					-21.5	4.5	3.2	2.16
21841	Fannerup F	<i>Sus scrofa</i>					-21.1	5.6	3.3	0.60
21842	Fannerup F	<i>Sus scrofa</i>	AAR-22740	5776 $\pm$ 26	5519 $\pm$ 26	4440-4335	-15.0	10.1	3.2	2.13
21814	Nederst	<i>Canis familiaris</i>	AAR-19692	5633 $\pm$ 28	5280 $\pm$ 28	4230-4040	-11.3	12.2	3.2	1.98
21815	Nederst	<i>Canis familiaris</i>					-11.6	12.5	3.3	0.43
21816	Nederst	<i>Capreolus capreolus</i>					-21.8	4.0	3.2	1.62
21817	Nederst	<i>Capreolus capreolus</i>	AAR-19693	6209 $\pm$ 35		5225-5070	-20.6	4.5	3.2	1.20
21818	Nederst	<i>Capreolus capreolus</i>	AAR-19833	6090 $\pm$ 32		5050-4955	-21.3	4.4	3.2	2.05
21820	Nederst	<i>Capreolus capreolus</i>					-21.3	4.6	3.3	1.18
21886	Nederst	<i>Canis familiaris</i>					-12.3	10.7	3.2	2.12
21887	Nederst	<i>Sus scrofa</i>	AAR-19834	5592 $\pm$ 31		4455-4370	-21.3	5.1	3.2	1.32
21888	Nederst	<i>Sus scrofa</i>					-21.4	4.3	3.3	1.68
21889	Nederst	<i>Sus scrofa</i>	AAR-19835	5595 $\pm$ 31		4330-4235	-22.5	5.1	3.3	2.84
21890	Nederst	<i>Capreolus capreolus</i>					-22.7	5.2	3.4	1.33
21821	Yderhede	<i>Capreolus capreolus</i>	AAR-19815	6420 $\pm$ 36		5470-5365	-24.2	4.0	3.2	6.29

21822	Yderhede	<i>Capreolus capreolus</i>					-23.8	5.4	3.2	4.85
21823	Yderhede	<i>Capreolus capreolus</i>					-22.2	2.6	3.3	11.27
21824	Yderhede	<i>Capreolus capreolus</i>					-23.1	3.8	3.5	0.49
21825	Yderhede	<i>Sus scrofa</i>					-22.2	5.6	3.2	6.10
21826	Yderhede	<i>Sus scrofa</i>	AAR-19816	6655 ± 35		5625-5555	-21.0	4.3	3.3	9.11
21827	Yderhede	<i>Cervus elaphus</i>					-22.6	3.2	3.2	4.39
21828	Yderhede	<i>Cervus elaphus</i>					-23.4	4.3	3.2	7.64
21829	Yderhede	<i>Cervus elaphus</i>					-23.2	4.9	3.2	8.34
21830	Yderhede	<i>Cervus elaphus</i>					-22.9	6.4	3.3	9.31
21831	Yderhede	<i>Cervus elaphus</i>	AAR-19817	6275 ± 33		5300-5225	-23.6	3.4	3.2	4.17
21832	Yderhede	<i>Cervus elaphus</i>					-23.4	3.8	3.2	2.62
21833	Yderhede	<i>Cervus elaphus</i>					-22.8	2.9	3.2	3.63
21834	Yderhede	<i>Cervus elaphus</i>					-21.4	3.5	3.2	3.66
21835	Yderhede	<i>Cervus elaphus</i>					-23.2	5.1	3.2	6.14
21836	Yderhede	<i>Cervus elaphus</i>					-22.4	5.6	3.3	1.25
21837	Yderhede	<i>Cervus elaphus</i>	AAR-19818	6372 ± 35		5465-5310	-22.4	4.5	3.1	3.34
21843	Østenkær	<i>Canis familiaris</i>					-20.4	8.6	3.1	9.80
21845	Østenkær	<i>Sus scrofa</i>					-23.1	3.4	3.1	3.87
21846	Østenkær	<i>Sus scrofa</i>					-22.1	5.2	3.2	3.89
21847	Østenkær	<i>Sus scrofa</i>					-22.3	4.3	3.3	4.88
21848	Østenkær	<i>Sus scrofa</i>					-22.2	4.2	3.2	5.95
21849	Østenkær	<i>Sus scrofa</i>					-21.4	3.2	3.2	7.45
21850	Østenkær	<i>Sus scrofa</i>					-21.5	3.3	3.1	7.69
21851	Østenkær	<i>Sus scrofa</i>					-22.2	3.4	3.1	10.75
21852	Østenkær	<i>Sus scrofa</i>					-22.5	5.1	3.2	7,09
21853	Østenkær	<i>Sus scrofa</i>					-23.2	3.5	3.2	3.26
21854	Østenkær	<i>Sus scrofa</i>					-22.4	3.9	3.3	3.26
21855	Østenkær	<i>Capreolus capreolus</i>	AAR-19819	5136 ± 28		3985-3820	-25.0	4.0	3.2	5.65
21856	Østenkær	<i>Capreolus capreolus</i>					-22.1	3.5	3.2	5.39
21857	Østenkær	<i>Capreolus capreolus</i>					-24.5	3.3	3.2	6.32
21858	Østenkær	<i>Capreolus capreolus</i>					-22.4	4.5	3.3	3.38
21859	Østenkær	<i>Capreolus capreolus</i>					-21.1	2.4	3.3	3.19
21860	Østenkær	<i>Capreolus capreolus</i>					-22.5	2.6	3.3	5.05
21862	Østenkær	<i>Capreolus capreolus</i>	AAR-19820	5255 ± 27		4225-3990	-23.4	4.4	3.2	4.15
21863	Østenkær	<i>Capreolus capreolus</i>	AAR-19821	5055 ± 25		3945-3795	-23.0	4.7	3.4	2.25
21864	Østenkær	<i>Capreolus capreolus</i>					-22.3	4.2	3.3	4.47
21865	Østenkær	<i>Capreolus capreolus</i>					-23.3	4.5	3.2	5.61
21866	Østenkær	<i>Cervus elaphus</i>					-22.2	4.9	3.3	2.78

21867	Østenkær	<i>Cervus elaphus</i>					-23.1	2.7	3.2	3.45
21868	Østenkær	<i>Cervus elaphus</i>					-23.0	4.7	3.3	5.63
21869	Østenkær	<i>Cervus elaphus</i>					-22.1	2.7	3.3	3.47
21870	Østenkær	<i>Cervus elaphus</i>					-22.6	5.9	3.3	4.05
21871	Østenkær	<i>Cervus elaphus</i>					-23.1	4.4	3.3	2.76
21872	Østenkær	<i>Cervus elaphus</i>					-22.8	4.0	3.2	3.81
21873	Østenkær	<i>Cervus elaphus</i>					-22.7	3.4	3.3	4.07
21874	Østenkær	<i>Cervus elaphus</i>					-21.2	2.8	3.2	3.67
21875	Østenkær	<i>Cervus elaphus</i>					-23.1	2.9	3.2	4.41
21876	Østenkær	<i>Cervus elaphus</i>					-21.6	4.0	3.3	4.34
21877	Østenkær	<i>Cervus elaphus</i>					-21.7	4.5	3.3	3.14
21878	Østenkær	<i>Cervus elaphus</i>					-22.7	5.2	3.3	4.93
21879	Østenkær	<i>Cervus elaphus</i>					-22.2	3.3	3.3	5.02
21880	Østenkær	<i>Cervus elaphus</i>	AAR-19822	5472± 34		4355-4265	-23.2	2.7	3.2	11.58
21881	Østenkær	<i>Cervus elaphus</i>					-23.5	3.2	3.3	4.23
21882	Østenkær	<i>Cervus elaphus</i>					-23.2	4.3	3.3	8.04
21883	Østenkær	<i>Cervus elaphus</i>					-21.0	2.6	3.2	3.56
21884	Østenkær	<i>Cervus elaphus</i>					-21.8	2.8	3.2	5.01
21885	Østenkær	<i>Cervus elaphus</i>	AAR-19823	5363±32		4325-4075	-23.3	4.5	3.2	6.85

3. Results

The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values are presented in Table 1 and summarised graphically in Fig. 3. The $\delta^{13}\text{C}$ values of the red deer (n=36) from the four sites range from -20.0 to -23.6 ‰ and the $\delta^{15}\text{N}$ values range from 2.7 to 5.9 ‰. The values of roe deer (n=20) are similar, with $\delta^{13}\text{C}$ values from -20.6 to -25.0 ‰ and $\delta^{15}\text{N}$ values ranging from 2.6 to 6.4 ‰ and the similarity is paralleled by the isotope values of the wild boar samples (n=20) from Nederst, Yderhede and Østenkær, with $\delta^{13}\text{C}$ values ranging from -21.0 to -23.1 ‰ and $\delta^{15}\text{N}$ values ranging from 3.3 to 5.6 ‰. Table 2 shows the summary statistics of all of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements conducted in this study.

Table 2. Summary statistics for the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ measurements of wild boar, red deer, roe deer, humans and dogs from the four sites.

Site	Species	n	$\delta^{13}\text{C}$ (‰) mean	±	$\delta^{15}\text{N}$ (‰) mean	±
Fannerup F	<i>Homo sapiens</i>	2	-11.05	0.35	15.65	1.91
Fannerup F	<i>Capreolus capreolus</i>	1	-21.7		6.4	
Fannerup F	<i>Cervus elaphus</i>	5	-20.52	0.54	4.48	0.25
Fannerup F	<i>Sus scrofa</i>	8	-17.34	3.78	8.39	3.13
Nederst	<i>Canis familiaris</i>	3	-11.73	0.51	11.8	0.96
Nederst	<i>Capreolus capreolus</i>	4	-21.25	0.49	4.38	0.26
Nederst	<i>Sus scrofa</i>	3	-21.73	0.67	4.83	0.46
Nederst	<i>Capreolus capreolus</i>	1	-22.70		5.20	
Yderhede	<i>Capreolus capreolus</i>	4	-23.33	0.88	3.95	1.15
Yderhede	<i>Sus scrofa</i>	2	-21.6	0.85	4.95	0.92
Yderhede	<i>Cervus elaphus</i>	11	-22.85	0.63	4.33	1.1
Østenkær	<i>Canis familiaris</i>	1	-20.4		8.6	
Østenkær	<i>Sus scrofa</i>	10	-22.29	0.58	3.95	0.74
Østenkær	<i>Capreolus capreolus</i>	10	-22.96	1.15	3.81	0.82
Østenkær	<i>Cervus elaphus</i>	20	-22.51	0.74	3.78	0.99

These values all match our expectations to the diet of animals living in a terrestrial environment dominated by C_3 plants. Some of these animals were probably broadly contemporary, but certainly not all, considering the total time-range of the sites. Nonetheless, they all lived under similar environmental conditions during the Atlantic period. The isotope values of the wild boar from Nederst, Yderhede and Østenkær suggest that they subsisted chiefly on a plant-based diet.

This terrestrial diet is, however, not observed among all the wild boar from Fannerup F as their $\delta^{13}\text{C}$ values range from -21.5 to -11.7 ‰ and $\delta^{15}\text{N}$ values range from 4.5 to 12.6 ‰. The isotope values of four out of eight wild boars sampled from Fannerup F, are noticeably enriched compared to those of the deer from the same site and other wild boars dated to the

Ertebølle period in Denmark and North Germany (Fig. 4). There are significant differences between the four enriched wild boars from Fannerup F and the 24 wild boars analysed in this and other Danish studies; t-test $\delta^{13}\text{C}$ $p=0.0016$ and $\delta^{15}\text{N}$ $p=0.0022$ (Craig et al. 2006, Ritchie et al. 2013). The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values indicate that a substantial amount of the dietary proteins derives from marine food sources. In fact, they are very similar in value and spread to $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of domesticated dogs from the Ertebølle culture (Fig. 5). All of the specimens with enriched carbon isotope values were ^{14}C dated, placing three of the pigs in the early Ertebølle and one in the late Ertebølle period.

Figure 3. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of wild boar from Fannerup F and of red deer, roe deer, wild boar, dogs and humans from Nederst, Yderhede, Østenkær and Fannerup F.

Figure 4. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the wild boar from Fannerup F and several other wild boar dated to the Ertebølle culture analysed from various sites in Denmark and North Germany (Craig et al. 2006, Krause-Kyora 2011, Ritchie et al. 2013).

Figure 5. $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the wild boar from Fannerup F and all analysed humans and dogs from Danish Ertebølle and Funnel Beaker sites (Richards & Koch 2001, Richards et al. 2003, Richter & Noe-Nygaard 2003, Fischer et al 2007a, Fischer et al. 2007b, Price et al. 2007, Ritchie et al. 2013, Brinch Petersen 2015). Dogs not attributed to a specific period are not accurately dated but fall either within the Mesolithic or the Neolithic.

The bones of the eight wild boars are all fragmented and represent different anatomical parts. Sample no. 21810 is a phalange, no. 21811 and no. 21838 are mandible fragments, no. 21812 and no. 21841 are scapula fragments, no. 21813, no. 21842 are different fragments of the radii and no. 21840 is a pelvis fragment (Fig. 6). Despite the fragmentation of bone pieces, the individual bone size, find context, time-range and isotope values support the argument for several individuals. The osteological examination of the four wild boars with high $\delta^{13}\text{C}$ values

indicates an age at death of around 0.5 to 1.0 years, which is comparable to the pattern of slaughter age we know from other Ertebølle settlements (Enghoff 2011).

Figure 6. *The four wild boar bone fragments from Fannerup F.*

4. Discussion

Isotope values on par with domesticated and marine-fed dogs as well as humans among the four wild boar suggest that at least in this part of Denmark, a longer-term trajectory towards symbiotic human-pig relationships had been underway some time prior to the transition to the Neolithic dated to just after 4000 cal BC. At the same time, the presence of wild boar with

carbon isotope compositions typical of terrestrial C₃ plant dominated environments at the same site suggests a continuation of wild boar hunting in the surrounding forests. Although sample size does remain small, these strongly contrasting values together indicate substantial variation in how these hunter-gatherer-fishers interacted with *Sus*, suggesting that, contrary to previous assumptions, local Mesolithic group may have been controlling or managing pigs at an earlier time, and well before the Neolithic.

There are numerous caveats, however: Wild boars and domesticated pigs are opportunistic omnivores (Schley & Roper 2003) and will exploit available food resources in their immediate environment – including marine resources. We know of well-documented modern cases in which wild pigs have been feeding of marine resources along the beaches in Komode, Indonesia (Masseti 2007). Furthermore, several isotope studies from later prehistoric and historical periods have yielded isotope values from pigs, which indicate fodder that includes marine sources (Richards et al. 2006, Kosiba et al. 2007, Mulville et al. 2009, Jones et al 2012). In particular, four pigs from three first millennium sites in Greenland show feeding on marine food, with mean $\delta^{13}\text{C}$ values at -17.1 ± 0.7 ‰ and mean $\delta^{15}\text{N}$ values at 11.2 ± 0.4 ‰ (Nelson et al. 2012) similar to the isotope values of the four wild boar reported here.

Yet, the amount of marine food required to attain the $\delta^{13}\text{C}$ values recorded on the isotopically enriched wild boar from Fannerup F is substantial; maybe up to half of the dietary protein in the diet. We argue that this enrichment is unlikely to be the result of simply feeding on what the Ertebølle occupants left behind, when the shell-middens were periodically vacated.

As wild boars are omnivorous, their isotope values potentially reflect very complex feeding patterns (Rowley-Conwy 2013). Wild boar have no particular food preference except plant material, which is the primary food source. However, studies indicate that boar may prefer food that is nutritious and easily digestible, such as acorns, fungi etc. (Ballari 2014). Hamilton et al. (2009) found that Neolithic pigs had higher $\delta^{13}\text{C}$ values than pigs from the Iron Age, suggesting that these earlier pigs had been feeding on, for instance, fungi. Fungi are high in protein and globally comparative studies show that they show substantial variation in their isotope values: $\delta^{13}\text{C}$ values range between -31.7 and -19.0 ‰ and $\delta^{15}\text{N}$ values range between -7.1 and 21.8 ‰ (O'Regan et al. 2016). Thus, the intake of fungi cannot explain the high $\delta^{13}\text{C}$ values of the four wild boar, although it could have contributed to the elevated $\delta^{15}\text{N}$ values. The intake of fungi as well as perhaps a larger number of nuts can, however, not completely account for the enriched $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values in the case of the four Fanneup F wild boars either. The shell midden is located close to Kolindsund, making it possible for wild boar to feed on the salty marsh, eventually elevating their isotope values comparably to studies of sheep at Orkney (Britton et al. 2008, Schulting et al. 2017). Yet, the increase of the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of Orkney sheep is around 3 ‰, and cannot explain the high values of the four wild boar. Although wild boars are known to wean their young at around 3-4 months, wild boar piglets begin to seek food by themselves already after a few weeks (Baagøe & Jensen 2007), making it unlikely that mother's milk intake is accountable for the high $\delta^{15}\text{N}$ values in our samples (Ambrose & DeNiro 1986, Jenkins et al. 2001).

A parallel to the wild boar specimens from Fanneup F may be found in those from Grube-Rosenhof, which Krause-Kyora et al. (2013) claim to have been domesticated pigs kept by Ertebølle groups. Grube-Rosenhof is located in current Schleswig-Holstein along the Baltic

coastline. The $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the specimens E24 (Krause-Kyora 2011) are within the expected range of wild boar (e.g. Craig et al. 2006, Krause-Kyora 2011, Ritchie et al. 2013). Contrary to the specimens from Fannerup F, those from Grube-Rosenhof show no sign of marine protein consumption. This lack of a marine dietary component in the Rosenhof pigs is in striking contrast to the documented presence of around 4,500 fish bones at the site (Goldhammer 2008), indicating that fishing must have been an important part of the subsistence activities and hence the diet at the site, yet not included in the diet of the resident and potentially domesticated pigs. At the very least, the differences in isotopic signatures between these two broadly contemporary specimens suggest that if the Rosenhof pigs were kept as domesticated pigs, it must have been in a manner quite different to the management of wild boar at Fannerup F. These management regimes – if that is what we are seeing here – resulted in different feeding conditions for the individuals at the two sites.

The closest parallel to the enriched isotopes values of the wild boars is in fact found in contemporaneous domesticated dogs. Their values are very similar – especial the values of wild boar no. 21812 are almost identical to those of the two dogs from Nederst. The similarities between the carbon and nitrogen isotope values of the wild boar and the dogs may indicate a loose management system of wild boar at Fannerup F, where the wild boar were left to forage the area surrounding the settlement and scour for food in the shell-middens.

By the end of the Mesolithic period there is evidence of a more sedentary lifestyle with Ertebølle foragers living more permanently at key sites (Zvelebil 2008, Blankholm 2008). We see an increase in the use of fish weirs, which require supervision and must be maintained

continuously. They require a substantial amount of effort and investment in a tightly circumscribed geographic area. Furthermore, the construction and maintenance of fish weirs requires large numbers of branches, which is often interpreted as evidence of wood management by the Ertebølle Culture (Zvelebil 1994, Davies et al. 2005, Zvelebil 2008, Bishop et al. 2015). Consequently, if Ertebølle groups were more sedentary and managed woods, it would also be conceivable that the management of animals such as *Sus scrofa* was part of their evidently complex subsistence strategies.

5. Conclusion

There is little doubt that four of the wild boars from Fannerup F fed on marine protein. We do not claim to understand the extent of the management – if any – completely but propose that it was maintained over some time or that similar habits emerged repeatedly within the same cultural and ecological context and the same micro-region. The wide distribution of ¹⁴C dates indicates a longer-lasting interaction of marine-oriented hunter-gatherer-fishers with wild boars at the site. By foraging on and around the shell-middens, the wild boar would have exploited a resource that was not a usual part of their diet: human food waste.

The food waste inadvertently formed a novel niche component for these *Sus*, one constructed by humans. Albeit probably not fully realised in the Mesolithic of southern Scandinavia, such constructed niches may have directly led to opportunities for domestication of the wild boar: The domestication of *Sus scrofa* and other animals, as well as of plants, all arose from pre-existing management systems (Smith 2007). Zeder (2015: 3192) states that ‘in order for management to result in domestication, a sustained multigenerational relationship must develop between the manager and the managed from which both reap mutual, although not

necessarily symmetrical benefits. Sustaining the relationship over the long term requires that both partners undergo modifications (genetically driven or facultative) that enhance the benefits each accrues'. Changes in genetics and morphology may eventually result in new domesticated species, distinctly different from their wild ancestors (Smith 2007).

Domestication was, however, a long process and the application of, for instance, bio-molecular methods may reveal different stages of the domesticating process, whilst isotope analysis may point to nutritional changes generated by human management long before morphological changes set in and, even further downstream, become distinguishable in the teeth or skeleton.

In this study, only one line of investigation was followed, which is not sufficient to fully reconstruct the possible management of wild boar by the Ertebølle hunter-gatherer-fishers from Fannerup F, especially given the small sample size currently available and the evident variability in *Sus* feeding habits. A larger stable isotope study, which examines a larger set of *Sus scrofa* remains from the site of Fannerup F as well as remains from other nearby shell-middens, along with DNA analyses and morphological studies, would allow us to gain a better understanding of possible animal husbandry in the Late Mesolithic Ertebølle culture. Yet, even if only one local group of Ertebølle foragers from the Danish area was managing wild boar in the centuries prior to the introduction of the Neolithic package, it would raise further challenges with regards to our current understanding of the Ertebølle culture.

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