CHAPTER 4

Lipid residue analysis on Swifterbant pottery (c. 5000–3800 cal BC) in the Lower Rhine-Meuse area (the Netherlands) and its implications for human-animal interactions in relation to the Neolithisation process

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Lipid residue analysis on Swifterbant pottery (c. 5000–3800 cal BC) in the Lower Rhine-Meuse area (the Netherlands) and its implications for human-animal interactions in relation to the Neolithisation process

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ABSTRACT

This paper focuses on the functional analysis of Swifterbant pottery (c. 5000–3800 cal BC) in the Lower Rhine-Meuse area (the Netherlands). It examines pottery use across the transition to agriculture and aims to assess temporal changes in human-animal relations during the 5th millennium BC in the Lower Rhine-Meuse area through lipid residue analysis. We conducted lipid residue analysis of 49 samples from four Swifterbant sites: Hardinxveld-Giessendam Polderweg, Hardinxveld-Giessendam De Bruin, Brandwijk-het Kerkhof, and Hazendonk. A combined approach using both GC-MS and GC-C-IRMS of residues absorbed into the ceramic was employed to identify their context. Their context was then compared to published faunal datasets to present the relative abundance of taxa detected in the lipid residues. Evidence of processing freshwater fish was found in all sites, presenting that it was a continuous and primary function of Swifterbant pottery in the Lower Rhine-Meuse area starting from its first appearance at c. 5000 cal BC till the end of 5th millennium BC regardless of vessel form, size, decoration or temper. The results of our analysis also present temporal changes in the exploitation of food resources from the early to the late 5th millennium BC. From the mid 5th millennium BC onwards, vessels were also used to process different ranges of foodstuffs such as terrestrial resources and dairy products. The identification of dairy residue is the first direct evidence so far from Swifterbant pottery. We tentatively explain these results as an indication of presence of different culinary practices that had developed through the 5th millennium in the Lower Rhine-Meuse area and that the use of Swifterbant pottery is a direct reflection of changing cultural preferences on food preparation and consumption.

1. Introduction

The term Neolithisation usually describes the transitional stages from the last hunter-gatherer communities to the first farming societies. The Neolithisation process, its timing and tempo, have traditionally been studied through observing changes in the subsistence economy, i.e. the inception of domesticated animal and plant remains, and through associated changes in material culture, such as pottery and stone tools. More recently, organic residue analysis has been used to examine both hunter-gatherer and early agricultural pottery use to look at economic change and offer new perspectives regarding culinary change and cooking practices at this important transition in prehistory. A clear pattern emerging from this growing body of research is the discrepancy between the use of hunter-gatherer pottery, entirely from northern Europe, and early farmer pottery from southern, central and Atlantic Europe. Hunter-gatherer pots were frequently used for cooking both marine and freshwater aquatic resources, as observed in the earliest vessels to appear in mid-6th millennium cal BC in north-eastern Europe (i.e. Narva-type pottery in southeastern Baltic) (Oras et al., 2017; Robson et al., 2019) and 5th millennium cal BC in northern Europe (i.e. Ertebølle pottery (EBK) in southwest Baltic, although Ertebølle ceramics were also used for processing of terrestrial animal and plant resources; Courèl et al., 2020; Craig, 2007, 2011; Heron et al., 2013; Papakosta, 2019; Philippson and Meadows, 2014). This contrasts markedly with the early farming pottery outside of northern Europe where, with a few notable exceptions (Cramp et al., 2019), aquatic resources are virtually
absent and ruminant meat and dairy products are frequently found (Guiry et al., 2016; Cramp et al., 2014, 2019; Smyth and Evershed, 2015; Debono-Spiteri et al., 2016; Cubas et al., 2019, 2020).

Although both hunter-gatherer pottery and early agricultural pottery have been studied in some detail (Craig et al., 2007; Dolukhanov et al., 2010; Povlsen, 2014; Kriiska et al., 2017; Oras et al., 2017; Hommel, 2018; Bondetti et al., 2019; Courel et al., 2020; Cubas, 2019), there have been relatively fewer comparisons of pottery use across the transition to agriculture. Such comparisons are only possible in northern Europe, where the tradition of pottery use by hunter–gatherer communities was already established prior to the arrival of farming. In some regions, the arrival of agriculture is accompanied by marked changes in pottery forms and manufacturing techniques. Residue analysis of pottery sequences that span the arrival of agriculture, such as the EBK to Funnel Beaker (TRB) in southern Scandinavia (c. 4000 cal BC) (Craig et al., 2011; Isaksson and Hallgren, 2012; Sørensen and Karg, 2014; Sørensen, 2017) and ‘subneolithic’ to Corded Ware (CWC) in southeastern Baltic (c. 2900/2800 cal BC) (Piličiauskas et al., 2017; Cramp et al., 2014; Heron et al., 2015; Robson et al., 2019) show a mixture of traditional hunter-gatherer subsistence strategies, including exploitation of aquatic resources, and the early farming subsistence economies, often including dairy products. Unlike other early European farmers, in northern Europe aquatic products continued to be processed in pottery beyond the arrival of farming and perhaps were influenced by pre-existing indigenous culinary practices.

Here we examine pottery use across the transition to agriculture in the Lower Rhine-Meuse area. In this region pottery began to be produced at c. 5000 cal BC by hunter-gatherers, known as the Swifterbant tradition. At around 4500–4400 cal BC, there is some evidence that domesticated animals were incorporated into the Swifterbant economy followed by cereal cultivation at around 4300–4000 cal BC (Cappers and Raemaekers, 2008; Çakırlar et al., 2020). Unlike other regions of northern Europe, these introductions were not accompanied by major changes in pottery forms or manufacturing techniques. Nevertheless, it is not known whether the use of pottery changed in this region with the arrival of domesticated animals and plants. Previous organic residue analysis of pottery from three of the Swifterbant type sites (Swifterbant S2, S3, S4), dating to the end of the sequence (c. 4300–4000 cal BC), show no evidence of domesticated animal products (Demirci et al., 2020) although domesticated cereals have been morphologically identified in the charred surface deposits of some vessels (Raemaekers et al., 2013). In this study, we examine a unique chronological transect of Swifterbant activity in the Lower Rhine-Meuse area. By comparing pottery use and faunal assemblages, we aimed to assess temporal changes in human-animal relations during the 5th millennium BC.

2. Archaeological sites

The lipid analysis was carried out on four Swifterbant sites in the Lower Rhine-Meuse area: Hardinxveld-Giessendam Polderweg (hereafter Polderweg), Hardinxveld-Giessendam De Bruin (hereafter De Bruin), Brandwijk-het Kerkhof (hereafter Brandwijk) and Hazendonk (Fig. 1). These sites provide the best sequence of Swifterbant pottery in the Lower Rhine-Meuse area, therefore allowing us to study the use of ceramics while across the transition to farming in the area. The Lower Rhine-Meuse area is a river delta in the Netherlands formed by the confluence of the Rhine and the Meuse rivers. At the end of the Late Pleistocene, the large riverbeds held relatively small rivers and the lack of vegetation cover allowed the sand at the surface to be transported by wind. As a result, a large number of river dunes were formed. From ca. 6000 BCE onwards, the sea level rise resulted in a rise of the groundwater in the area. In its turn, this caused sedimentation of peat and clay. As a result, the archaeological sites discussed here are located in a riverine landscape, where the river dunes provided sparse dry spots for occupation and exploitation (Louwe Kooijmans, 1974, 1993, 2003).

The occupation history of the four sites covers a period from c. 5500 to 3700 cal BC. All four sites were inhabited repeatedly. In this article we focus on the period c. 5000–3820 cal BC, from the oldest ceramics in Swifterbant style (Polderweg phase 2/ De Bruin phase 2; Raemaekers, 2011) to the end of the Swifterbant ceramic tradition (Brandwijk L60; Raemaekers, 1999: 52–53) in the area.

Overall, the pottery from the Lower Rhine-Meuse area sites fits the general description of Swifterbant pottery (Raemaekers: 30–31, 45–55, 63–65, 1999; Raemaekers, 2011; Raemaekers and de Roever, 2010; Louwe Kooijmans, 2010). The pottery from the four sites is characterised by S-shaped, mostly open forms with slightly pointed or rounded bases.
It was constructed using the coiling technique, with rim diameters varying from 15 to 40 cm (with the median diameter of 20 cm) and wall thicknesses from 5 to 12 mm (with the median thickness of 10 mm). In terms of fabric, all four sites produce extremely coarse pottery with mostly uneven surfaces. The surface treatment is rare and when present, varies between smoothing, smearing, roughening, and polishing. The most common inclusion for the Polderweg and De Bruin sherds is grit, although some grit and plant material appear as well. Almost all the sherds from Brandwijk and Hazendonk indicate plant material and/or grit as the main temper materials along with rare appearance of grit, sand, and mica. In terms of decoration, there is a temporal variation between the characteristics of the earlier Swifterbant pottery from Polderweg and De Bruin and later assemblages from Brandwijk and Hazendonk. In the earlier pottery assemblages, the decoration is uncommon and when present, it only appears as a series of spatula impressions on the top of the rim. In contrast, later assemblages present a higher distribution of vessels with wall and surface-covering decoration. Wall decorations vary between spatula impressions, thumb impressions, and hollow-circular impressions, while surface-covering decorations consist of either fingertip/nail or hollow spatula impressions. This temporal variation in decoration between earlier and later Swifterbant pottery is well illustrated in the sherds that have been subjected to lipid residue analysis (Supplementary Dataset-1).

All four sites used a broad range of subsistence strategies, exploiting a wide range of animal and plant taxa, including large and small game, terrestrial and aquatic, fowl and fish, nuts, and berries. This wide scope remained consistent throughout the period under study (Brinkhuizen, 1979; Zeiler, 1997; Raemaekers, 1999; Louwe Kooijmans, 2003, 2001a, 2001b, 2007; Oversteegen et al., 2001). Deer (Cervidae), Sus sp., otter (Lutra lutra) and beaver (Castor fiber) are the most abundant mammals recovered at all sites. Otter and beaver were hunted in large numbers, and their meat as well as fur were exploited (Zeiler, 1997). It is difficult to assess the role of domestic animals in subsistence during this period (Rowley-Conwy, 2013; Çakırlar et al., 2020; Dusseldorp and Amkreutz, 2020). Analysis of mitochondrial DNA of four Sus teeth of unclear phenotype from the late 5th millennium BC Swifterbant site S4 shows the prevalence of European maternal lineages in Sus there (Krause-Kyora, 2011; Kraneburg and Prummel, 2020). However, since intermixing between local wild boar and domestic pigs with origins in the Near East was very common (Franz et al., 2019), information about maternal lineages alone adds little to the understanding of the nature of pig/goat use at this juncture. Bos sp. first appear in the younger phases of De Bruin, and always remain in low numbers (Çakırlar et al., 2020). Although small sample sizes do not allow reconstructing population-wide patterns in morphology and mortality, the absence of aurochs (Bos primigenius) in Polderweg and De Bruin phase 1, and the size and age-at-death variation represented by Bos specimens may suggest the presence of domesticated cattle herds possibly in De Bruin phase 3 and Brandwijk, and more probably in Hazendonk.

The most secure indication for the presence of domesticated animals in the archaeological record of the Lower Rhine-Meuse area in the Swifterbant period is the few remains of sheep or goat bones at De Bruin and Brandwijk. The earliest directly dated domesticated animal specimen in the region comes from De Bruin and is dated to 4520–4356 cal BC (Çakırlar et al., 2020; Table 13.5). Since sheep and goat are not native to Europe, it is certain that these animals must have been introduced to the area from regions to the south or east where farming was already established at this time. Although osteomorphological analyses suggest that some remains might belong to the same individual, decreasing the total number of identified sheep/goat specimens while increasing the uncertainties in their interpretation (Çakırlar et al., 2020). Future studies amalgamating zooarchaeology with high-resolution radiocarbon, stable isotope, and palaegenomic analyses is needed to resolve this issue.

Given the ambiguity in the identification of wild vs. domesticated suids and bovids, ‘Sus sp.’ ‘Bos sp.’ are referred to hitherto. This classification also reflects the specificity that can be achieved by lipid residue analysis, which is unable to distinguish wild from domesticated ruminant and porcine fats.

From the high frequency of fish bone remains, it is clear that fishing was a key activity at all sites. All sites provide clear evidence for freshwater (i.e. pike [Esox lucius], perch [Perca fluviatilis], catfish [Silurus glanis], carp family [Cyprinidae]), anadromous (i.e. sturgeon [Acipenser sturio]), eel (Anguilla anguilla), salmon/seat trout [Salmo salar cf. trutta], allis shad (Alosa alosa L.) and occasional appearance of marine (mullet family [Mugilidae]) species (Brinkhuizen, 1979; Zeiler, 1997). Bird bones are relatively less common compared to mammal and fish remains in all four sites and mainly comprise duck (Anatidae), especially mallard (Anas platyrhynchos).

The archaeobotanical remains indicate that gathering remained an important subsistence strategy throughout the 5th millennium BC. All sites show evidence of numerous remains of wild plant species including acorn, hazelnut, water caltrop, wild apple and various berries. Archaeobotanical analyses also present the introduction of possible small-scale crop cultivation in the Lower Rhine-Meuse area. Brandwijk phases L50 and L60 and Hazendonk phase 1 yielded emmer wheat (Triticum turgidum ssp. dicoccum) and naked barley (Hordeum vulgare var. nudum) from 4220 to 3820 cal BC and 4020–3960 cal BC onwards respectively (Fig. 6) (Bakels, 1981; Out, 2008, 2009). Moreover, the study of anthropogenic influence on the vegetation indicates a restricted clearance of woodland (i.e. Tilia sp., Quercus sp. and Alnus glutinosa) and development of open patches at Brandwijk and Hazendonk. This may imply small-scale local cultivation at these sites (Out, 2009). The same cereals were found at other sites of the Swifterbant culture (Out, 2009; Schepers and Bottema-Mac Gillavry, 2020), while several cultivated field were recovered at the sites at Swifterbant (Huisman et al., 2009; Huisman and Raemaekers, 2014; Raemaekers and De Roever, 2020), strengthening the interpretation of local cultivation instead of imported crops. We consider the period of c. 4300–4000 cal BC the introduction date of cereal cultivation in the Swifterbant culture.

All four sites are considered to be seasonally occupied, where the function did not change over time, but occasional year-round occupation cannot be excluded either (Louwe Kooijmans, 1993, 2001a, 2001b; Raemaekers: 59–61, 1999).

3. Material and methods

3.1. Sampling strategy

A total of 49 samples (Polderweg, n = 9; De Bruin, n = 17; Brandwijk, n = 14; and Hazendonk, n = 9) were subjected to lipid residue analysis, all representing individual vessels. Of all samples, 17 (4 from Polderweg, 3 from De Bruin, and 10 from Brandwijk) have traces of carbonised remains (foodcrust) on interior and/or exterior surfaces, indicating that they had been used for cooking. Samples were selected from the Swifterbant pottery phases of each site (see Table 1). Pottery from all four Swifterbant sites, Polderweg, De Bruin, Brandwijk, and Hazendonk, was subjected to lipid residue analysis (Supplementary Dataset-1).
were highly fragmented coursework. Therefore, the sample size of each site is constrained to individual vessel fragments that provided different typological and morphological features and are large enough to be sampled. When available, rim fragments were preferentially selected as experimental studies suggest that lipids tend to accumulate on the rim due to the boiling of food products in the ceramic vessels (Charters et al., 1993). However, base fragments and decorated body sherds were also analysed as they are also diagnostic fragments providing information on the typology and the morphology of the pot. During the process of selecting samples, the form, size, decoration, rim diameter, wall thickness, and temper were recorded (Supplementary Dataset-1).

3.2. Lipid residue extraction

Samples were drilled from the interior surface of each vessel and were subjected to lipid extraction by established standard one step acidified methanol protocol (Craig et al., 2013; Papakosta et al., 2015). All extractions were analysed by Gas Chromatography-Mass Spectrometry (GC-MS), using different columns and modes for identification of different biomarkers (i.e. aquatic biomarkers) (Hansel et al., 2004; Regert, 2011; Cramp and Evershed, 2014; Lucquin et al., 2018), and Gas Chromatography-Combustion-Isotope Ratio Mass Spectrometry (GC-C-IRMS) for the measurement of compound-specific carbon stable isotopic ratios of the two most abundant fatty acids; C16:0 and C18:0, according to previously described protocols (Craig et al., 2012). To assess the corresponding zoological evidence, published faunal datasets were re-evaluated to quantify the relative abundance of taxa detected in the lipid residues and the taxonomic identification of relevant specimens were checked. The zoological data were further assessed to reconstruct patterns in body part representation, fragmentation, and mortality, but either sample size or data inaccessibility due to deficiencies in records and their metadata, or both hampered data re-use. Further detailed information on the methods can be found in the Supplementary Materials-Methods.

4. Results and interpretations

4.1. Results of molecular analysis (GC-MS)

All samples (n = 49) yielded sufficient quantities of lipids required for interpretation (>5 μg g⁻¹) with a mean value of 122 μg g⁻¹ (ranging from 8 μg g⁻¹ to 1,343 μg g⁻¹) (Supplementary Dataset-1). In general, the lipid profiles obtained from each sample contained saturated fatty acids, ranging from C10:0 to C28:0, dominated by mid-chain saturated acids, palmitic acid (C16:0) and stearic acid (C18:0), respectively. The C16:0 and C18:0 ratios (P/S ratios) of all the samples are listed in the Supplementary Dataset-1. Thirty-four of all the samples yielded unsaturated fatty acids from C15:1 to C24:1, dominated by oleic acid (C18:1). Branched fatty acids (C12 – C25) were also identified in 43 of all the samples. Dicarboxylic acids are present in 28 samples (58%), all with C9 (azelaic acid), of which two also have C10. A total of 16 samples yielded cholesterol and its derivatives, indicating the presence of animal fats.

In addition, biomarkers for aquatic products were identified in 31 of all 49 samples (Supplementary Dataset-1). Co-occurrence of apo(α-alkylphenyl) alkanolic acids (APAAs), with carbon atoms ranging from 18 to 22, and isoprenoid fatty acids which are TMTD (4,8,12-trime-thyltridecanoic acid), pristanic acid (2,6,10,14-tetramethylpentadecanoic acid), and phytanic acid (3,7,11,15-tetramethylhexadecanoic acid) is accepted as the established criteria for identifying aquatic lipids in the ancient pottery (Evershed et al., 2008a; Hansel et al., 2004; Craig et al., 2007; Cramp and Evershed, 2014; Heron et al., 2015). As APAAs are formed by heating (≥200°C, >5h; Bondetti et al., 2020) of mono and polyunsaturated fatty acids, their presence shows that these pots were used for cooking.

While TMTD is considered more of a characteristic of aquatic oils, pristanic and phytanic acids are found in both aquatic and ruminant resources (Ackman and Hooper, 1968; Heron and Craig, 2015). To investigate the origin of phytanic acid found in the samples, we study the ratio of the two diastereomers of phytanic acid (3S,7R,11R,15-py-htyic acid (SRR) and 3R,7R,11R,15-py-thylic acid (RRR)) as the SRR isomer tends to predominate in aquatic oils (>75.5% relative abundance) compared to ruminant fats (Lucquin et al., 2016). In total, 61% of the samples with phytanic acid meet this criterion. For the remaining samples, the SRR/RRR ratio is either not available or falls within both the aquatic and ruminant range. Further 16 samples yielded partial aquatic biomarkers, containing C18 APAAs and at least one isoprenoid acid which is also an indication of possible process of aquatic resources in these vessels (Evershed et al., 2008a; Heron and Craig, 2015), although not definitive.

Although the presence of C20 APAAs has been widely used to identify aquatic products in ancient pottery (Hansel et al., 2004; Cramp and Evershed, 2014), an experimental study undertaken by Bondetti et al. (2020) demonstrates that these compounds can also be formed by heating mammalian tissues. Nevertheless, this study found that the C20 APAAs in heated aquatic products are at much greater relative abundance compared to C18 components whereas the APAA C20/C18 Ratio was substantially lower in mammalian tissues. Based on their results, Bondetti et al. assign an APAA C20/C18 Ratio of 0.06 as the lower limit for the identification of aquatic products. Here, all four sites provide a significantly large number of beaver bone remains (Fig. 6) hence beaver may have been a commodity processed in pottery, particularly for rendering the fatty tail meat (Coles, 2006). To investigate, we measured the APAA C20/C18 in 12 Swifterbant vessels and found that in all cases the values were above 0.06 (varying between 0.16 and 0.76; Supplementary Dataset-1) and therefore corresponding to reference fish samples rather than the mammalian dataset that included beaver (Bondetti et al., 2020). For the remaining samples, the APAA C20/C18 ratio was not possible to measure accurately.

As further evidence for distinguishing aquatic products from beaver as well as dairy products, we also looked at the branched fatty acids (C15ββ and C15γγ) in samples with fully aquatic biomarkers (n = 31). Iso-branched fatty acids predominant in fish oils (Hauff and Vetter, 2010; Garnier et al., 2018), while anteiso- branched fatty acids are more predominant in beaver fat (Käkelä et al., 1996) and also in dairy products (Hauff and Vetter, 2010); the iso-branched fatty acids account for 59 ± 16% of the C15 and 59 ± 5% of the C17 branched fatty acids in fish oils, 38 ± 6% of the C15 and 34 ± 2% of the C17 branched fatty acids in dairy products and 19 ± 4% of the C15 and 35 ± 12% of the C17 branched fatty acids in beaver adipose and flesh tissue fats, the latter from Estonia, Russia and Canada (Caster fiber and Caster canadensis, n = 10; Supplementary Dataset-3). Of the samples from the Lower Rhine-Meuse Swifterbant vessels with fully aquatic biomarkers (n = 31), 61 ± 0.8% of the C15 and 53 ± 10% of the C17 branched fatty acids (Supplementary Dataset-1) are present as iso-fatty acids and therefore are comparable with fish oils rather than beaver fats or dairy products. It is important to note here that the potential effect of the burial environment on this ratio is not known and needs to be tested in further studies.

Finally, none of the samples yielded plant derived lipids (e.g. phytosterols) (Supplementary Dataset-1). It is important to mention here that these results are based on acid extraction and none of the samples have been subjected to solvent extraction to identify cereal derived lipids. Interestingly, the clear presence of carbonized macro remains of mature food plants found at all four sites suggest that these were processed as part of the food preparation (Out, 2009). In addition, archaeobotanical studies at Brandwijk and Hazendonk indicate the presence of micro remains (i.e. pollen) of crop plants in high amounts (Out, 2009). As naked barley and emmer wheat release the highest amount of pollen during threshing, its presence clearly indicates processing of cereal products at these two sites (Out, 2008, 2009). Although this can be explained by the application of other techniques not requiring ceramics to process food plants, we know that food plants have
a low lipid content and may be masked by other animal fats processed in pots (Colonese et al., 2017; Hammann and Cramp, 2018). This, therefore, makes it very difficult to identify the presence of food plants through lipid residue analysis. We also know that the scanning electron microscope (SEM) analysis on the carbonized surface deposits (food-crust) collected from another Swifterbant site, Swifterbant S3, has shown that the pots were also used for processing plant materials (Raemaekers et al., 2013). Given that, the absence of plant biomarkers in Swifterbant pottery through lipid residue analysis should be approached cautiously.

4.2. Isotopic identification of individual fatty acids (GC-C-IRMS)

In order to provide more information on the origin of the lipid residues, the carbon stable isotope values of palmitic (C_{16:0}) and stearic (C_{18:0}) acids were analysed by GC-C-IRMS. Analyses included 48 samples which yielded sufficient fatty acids (> 5 μg g^{-1}). The data from the samples are listed in and Supplementary Dataset-1. They are plotted in Fig. 3 against the reference ranges of authentic modern animal fats collected from the western Baltic, except for modern beaver fat which was collected from eastern Baltic.

Overall, the majority of the δ^{13}C values of C_{16:0} and C_{18:0} fatty acids from all four sites are consistent with freshwater organisms (Fig. 3). Of 31 samples with fully aquatic biomarkers, 27 plots in this range. Although beaver also plots within the freshwater range (Fig. 3), both APAA C_{20}/C_{18} ratios and iso to anteiso ratio of C_{15} and C_{17} branched fatty acids refute the possible presence of beaver in these pots. Therefore, there is compelling evidence that these vessels were regularly used for processing freshwater fish.

Three samples from Brandwijk and five samples from Hazendonk plot within the range of modern porcine and marine fats (Fig. 3c and d). Sus sp. is abundant at Brandwijk (30% of all identified mammal fragments in L50, Number of Fragments (NF) = 73; 22% of all identified mammal fragments in L60, NF = 99; See Supplementary Dataset-2). Sus sp. is also present at Hazendonk (10% of all identified mammal fragments in Hazendonk 1/2; NF = 167, and 11% of all identified mammals in Hazendonk 3; NF = 490) (Zeiler, 1997; Çakılar et al., 2019). While marine taxa are virtually absent from the zooarchaeological record of both sites, anadromous fish species are present in Brandwijk and Hazendonk. The species include sturgeon, salmon/sea trout, and allis shad (the latter only in Hazendonk) (Brinkhuizen, 1979). It is important to mention here that sturgeon represents a relatively large portion (3.1%, NF = 991 in L50; 3.8%, NF = 415 in L60) of the total fish bone remains at Brandwijk (Raemaekers, 1999: Table 3.27). Although it is
difficult to know the exact isotope values of sturgeon without its collagen analysis, the possibility of it being processed in the vessels cannot be ruled out for this site. Based on the faunal remains and on the fact that one of the three Brandwijk samples and all five of Hazendonk samples contain partial aquatic biomarkers (Supplementary Dataset-1), we can conclude that these samples contain a mixture of aquatic (mainly freshwater) and porcine derived lipids.

In Fig. 4, the $\delta^{13}C$ values of the C16:0 acid are also plotted against the difference between the two major fatty acids ($\Delta^{13}C = \delta^{13}C_{18:0} - \delta^{13}C_{16:0}$) (Supplementary Dataset-1). This enables us to differentiate ruminant adipose, non-ruminant, and dairy fats (Dudd, 1999; Craig et al., 2012, 2013; Cramp and Evershed, 2014; Taché and Craig, 2015). $\Delta^{13}C$ values lower than $-1\%$ are typical of ruminant fats (Dudd et al., 1998; Evershed et al., 2002; Copley et al., 2013; Craig et al., 2012). Seven samples from De Bruin plotted in the ruminant adipose fat range and another two in between non-ruminant and ruminant adipose fat ranges (Fig. 4b). Faunal material from De Bruin shows the presence of Bos sp. and sheep/goat (0.2% and 0.1% of identified mammal bones in Phase 2, NF = 1728; 4% and 1.8% in Phase 3, NF = 591, respectively) as well as red deer remains (~3.2% of identified mammal bones in Phase 2, NF = 1728; and in Phase 3, NF = 591) (Fig. 6B; Supplementary Dataset-2) (Louwe Kooijmans, 2007; Oversteegen et al., 2001; Amkreutz, 2013; Çakırlar et al., 2019, 2020). The presence of a series of cut and chop marks on these remains also indicates that they were processed for consumption (Clason, 1978). As three of these vessels have fully aquatic biomarkers and four of the remaining five are partially aquatic, we conclude that the residue is derived from a mixture of freshwater and ruminant fats.

One sample from Polderweg is in the ruminant adipose fat range (Fig. 4a). In terms of the presence of ruminant animals at Polderweg, faunal records indicate a total absence of domesticated animals and red deer covers only 0.8% of identified mammal bones (in Phase 2, excluding antlers, NF = 233) (Van Wijngaarden-Bakker et al., 2001; Çakırlar et al., 2019). In addition, this sample has fully aquatic biomarkers. However, it is known that even a minor contribution of ruminant fat can be detected given there is a strong bias against aquatic oils when mixed with ruminant fats due to the difference in fatty acid concentration between these products (Cramp et al., 2019). Based on these, we conclude that this residue may also be a possible mixture of lipids derived from aquatic and ruminant fats.

Finally, one sample from Brandwijk L50 (BR08) clearly plots below the limit for wild ruminant carcass fats (~4.3‰; Craig et al., 2012) (Fig. 4c), meeting widely accepted criteria for ruminant dairy fats (Copley et al., 2003; Evershed et al., 2008b; Debono-Spiteri et al., 2016). As this sample (BR08) has fully aquatic biomarkers, this residue likely contains a mixture of lipids derived from both aquatic and dairy sources. Although no other sample plot in the dairy range, it is important to mention that low quantities for dairy fats would not be detected using these criteria when mixed with relatively high quantities of non-ruminant lipids (including aquatic) (Debono-Spiteri et al., 2016; Cramp et al., 2019).
5. Discussion

5.1. Functional continuity of the Swifterbant pottery for freshwater fish processing

Our research provides new insight into the function of Swifterbant pottery, starting from its first appearance at c. 5000 cal BC, throughout the 5th millennium in the Lower Rhine-Meuse area. The molecular and isotopic evidence show that this pottery was heavily used for processing freshwater resources regardless of vessel form, size, decoration (Fig. 2) or temper (Supplementary Dataset-1). Processing of freshwater resources seems to have been the primary function of Swifterbant pottery, for over 1000 years, despite the introduction of domesticated animals and plants.

Similarly, previous studies have shown that aquatic resources were extensively processed in hunter-gatherer ceramics throughout northern Europe (Craig et al., 2007; Heron et al., 2015; Oras et al., 2017), although in some cases they were mixed with terrestrial products and foodplants (i.e. Ertebølle pottery; Courel et al., 2020; Papakosta, 2019). This practice continued beyond the arrival of agriculture. Recent residue analysis of vessels from three other Swifterbant sites, Swifterbant S2, S3 and S4 (ca. 4300–4000 cal BC) (Demirci et al., 2020) also shows a dominance of freshwater fish.

5.2. Economic importance of pig

Unlike Polderweg and De Bruin, Brandwijk and Hazendonk yielded evidence for porcine fats in the vessels. The vessels with porcine fats did not show any specific morphological or technological differences compared to the pottery assemblages as a whole. We conclude that the processing of Sus sp. changed from Brandwijk L50 onward. Although it is difficult to assess the importance of the Sus sp. in subsistence through lipid residue analysis, the combination of our results and the zooarchaeological record provides some clues about what might lie behind this change. Suid remains are abundant in the zooarchaeological assemblages of the Lower Rhine-Meuse area dating to the 6th millennium BC.
and they remain so in the 5th millennium BC (Fig. 6B). A recent study on the bone remains show that small-sized Sus sp., possibly representing domesticated pigs, are absent in Polderweg and De Bruin, while they appear in Brandwijk L60 (Çakırlar et al., 2020). The pig population at Brandwijk seems to have been culled at younger ages than the individuals exploited in Polderweg and De Bruin. Size and age-at-death data suggest a change in pig management, possibly with the appearance of smaller, domesticated pigs interbreeding with wild boar.

This change in pig management seems to correlate to the presence of porcine fat in the Brandwijk and Hazendonk vessels. Interestingly, the Sus sp. is represented almost exclusively by cranial and distal extremity elements (i.e. head and feet) in Brandwijk. While this pattern of body part representation is markedly different from Polderweg, De Bruin, and Hazendonk, the Brandwijk sample is relatively small (NF = 22 in both L50 and L60) and it is difficult to pinpoint what the differential body part representations mean. One possibility is that the Brandwijk inhabitants received only parts of the carcass, another is that the inhabitants of Brandwijk processed pork off site, with a cooking tradition that favoured heads and feet. Reported data allow us to calculate average Sus sp. fragment weight per assemblage (see Supplementary Dataset-2: Table 1), which shows a decreasing trend from Polderweg to De Bruin. Although bone weight can be influenced by post-depositional factors such as leaching and burning, and excavation methods such as sieving, it is considered a good index of carcass processing techniques (Gifford-Gonzalez, 2018). The reduced weight of Sus sp. fragments in the younger phases of De Bruin, Brandwijk, and Hazendonk may be associated with a new practice of

![Fig. 6.](image-url)
Cooking pork in pots.

5.3. Evidence of ruminant fats

Lipid residue analysis indicates a changing approach to processing ruminant resources in the pots from these four Swifterbant sites. It is only in De Bruin phase 3 that we see clear evidence of processing ruminant resources in the pots. While Polderweg has only one sample yielding ruminant fats, ruminant carcass fats are completely absent in Brandwijk and Hazendonk samples. The pots with ruminant fats do not deviate from the other pots in terms of their morphological or technological features. Therefore, processing ruminant resources in the pots may be explained with specific local cultural preferences in culinary practices and/or changing human-animal relations rather than any gross changes in subsistence strategies.

Zooarchaeological records show the presence of ruminant in all four sites (Supplementary Dataset-2) and various species of deer, Bos sp. and sheep/goat could be the source of these ruminant fats in the pots. There is one sample from Polderweg that yielded Δ13C values matching to ruminant adipose (see Fig. 4a, Supplementary Dataset-1). As domesticated ruminants seem absent from Polderweg, it is most likely that the vessel with adipose fat is derived from wild ruminants, such as deer or aurochs. If that is the case, although the combination of our results and the faunal data suggest that the samples from De Bruin with ruminant fats may indicate processing domesticated animals, processing wild ruminant food resources, possibly deer, in these pots is equally possible.

5.4. Dairy products in the Swifterbant pottery

Dairy is readily identifiable in prehistoric pottery throughout Europe (Craig et al., 2005, 2011; Spangenberg et al., 2008; Isaksson and Hallgren, 2012; Salgue et al., 2012; Heron et al., 2015; Cramp et al., 2019; Stojanovski et al., 2020) and it is considered to be one of the main drives of the introduction of domesticated animals into the subsistence economy (Copley et al., 2003; Dunne et al., 2012). However, direct chemical evidence for the presence of dairy in the Swifterbant culture has been lacking until now. In this study, we present the first evidence for dairy products in two Swifterbant vessels, one from Brandwijk L50 (Fig. 4c) and one possibly from De Bruin phase 3 (Fig. 4b).

One of the biggest challenges now, however, is to understand whether these one or two pots with dairy lipids are an under-representation of the wider use of dairy products in the Swifterbant culture or if they are the results of interactions with neighbouring farmer communities. Traditionally, one of the ways to study dairying is to reconstruct slaughter age and sex profiles based on the animal bones. High abundances of mature females, low numbers of mature males and high abundances of very young animals are seen as evidence for dairying (Payne, 1973). While Bos sp. and sheep/goat are present at both De Bruin and Brandwijk (Fig. 5, Fig. 6b; Caklar et al., 2019, 2020), the high fragmentation of the remains and the small size of the assemblages prevent us from profiling the age and sex of these animals. As a result, it remains uncertain whether these animals were kept for their meat or were also exploited for secondary products such as milk, butter and cheese.

Another type of analysis focuses on the ceramic characteristics of the vessels directly associated with dairy processing. Both Swifterbant vessel fragments containing dairy products are flask-like, have small diameters and are decorated with bird bone impressions around the neck (Supplementary Dataset-1; Fig. 2, BR08 and HR20). All the other pots from these assemblages have beaker shapes, larger diameters and are never decorated with bird bone impressions. The similarities between these two vessels further strengthens the interpretation of the De Bruin vessel as one involved in dairy processing and the shared notion about the characteristics of ‘dairy vessels’ between the pots of De Bruin and Brandwijk. This is consistent with the Funnel Beaker flasks from submerged coastal site Neustadt in Schleswig-Holstein, Northern Germany which were used for processing dairy (Saul et al., 2014). Our findings make further lipid analysis on more Swifterbant flask-like vessels as well as petrographic analysis of these assemblages the logical next step in order to test our results with a bigger data set and also to distinguish whether the ‘dairy vessels’ were produced on site or are vessels that were brought to the site, with their specific content.

6. Conclusion

The new data presented here clearly shows that processing freshwater fish was a continuous and primary function of Swifterbant pottery in the Lower Rhine-Meuse area, starting from its first appearance at c. 5000 cal BC till the end of 5th millennium BC. We argue that the main use of the pottery for processing freshwater fish among Swifterbant sites was a consistent and deliberate choice which was also maintained while the two main aspects of the Neolithization process (i.e. cereal cultivation and possibly animal husbandry) were introduced to the area. In this regard, our research contributes to the discussion of the pottery production in the hunter-gatherer societies and the function of the pottery through the Mesolithic-Neolithic transition in northern Europe. From our data, we suggest that the Mesolithic-Neolithic transition in the Lower Rhine-Meuse area was not a sudden event but more of a gradual process which was certainly influenced in part by the dynamics of intercultural encounters with neighbouring farming communities.

The results of our analysis also present temporal changes in the exploitation of food resources from the early to the late 5th millennium BC. In addition to the continuous exploitation of freshwater resources, we see that processing ruminant foodstuff becomes an important part of pottery use in the mid-5th millennium BC. Whether this is a result of the arrival of domesticated animals around the same time into the Lower Rhine-Meuse area or is evidence for the continuous exploitation of wild ruminant fauna, it presents a change in the ways of processing ruminant food resources and the use of pottery. This is followed by the first appearance of dairy products in the Swifterbant pottery. Although, at this point, we are not able to fully grasp the scale of dairy production, our study is important in terms of showing the first evidence of processing dairy in the Swifterbant pottery. It also allows us to propose that the De Bruin phase 3 is where we start to see a change in human-animal relations to such extent that we might talk about the start of the Mesolithic-Neolithic transition in the Lower Rhine-Meuse area.

By the late 5th millennium BC, we witness another change in the use of Swifterbant pottery in the Lower Rhine-Meuse area as the ruminant animal carcass fats completely disappear from the pots and get replaced by porcine fats. This kind of a shift in the use of pottery raises questions about changing human-animal relations in terms of animal management and culinary practices in Swifterbant culture. In view of the limited understanding of the animal bones present, lipid residue analysis provides a strong method to gain insights into human-animal relations during the 5th millennium BC.

Another outcome of our study relates the functional variation to the ceramic characteristics of the Swifterbant pottery. It appears that beaker-shaped vessels were used for processing freshwater and terrestrial resources, while processing dairy products was associated with flasks - a pottery shape associated with dairy products in other areas as well (Saul et al., 2014). This is the first time we are able to present functional variation in the Swifterbant pottery through lipid residue analysis. Therefore, this needs to be examined with further research such as petrographic analysis to determine the origin of these “dairy vessels” which would help us to gain insight into the origin of the content of the pots, contributing to the discussion of cultural preferences on culinary practices, human mobility and/or interaction between different groups in the Lower Rhine-Meuse area.

Differences in pottery use between these four Swifterbant sites cannot be explained only by the differences in availability or accessibility of the resources in their immediate or surrounding environment. It is known that diet can relate to different subsistence economies.
determined by both local environment and cultural change. However, zooarchaeological and archaeobotanical records present a continuous exploitation of similar and diversified faunal/floral resources in all four sites. Therefore, we argue that different culinary practices developed through the 5th millennium in the Lower Rhine-Meuse area and that the use of Swifterbant pottery may be a direct reflection of changing cultural preferences on food preparation and consumption which requires further research.

Overall, our current study provides an important insight into the function of the hunter-gatherer pottery, broadening our knowledge about the Swifterbant culture north-western Europe. It also shows that additional analysis on the bone material is needed to contribute to the debate of changing human-animal relations and Mesolithic-Neolithic transition in the Swifterbant culture.

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All authors gave their final approval for publication.
SUPPLEMENTARY MATERIALS
(METHODS and SUPPLEMENTARY DATASETS 1, 2, 3)

for
Lipid residue analysis on Swifterbunt pottery (c. 5000–3800 cal BC) in the Lower Rhine-Meuse area (the Netherlands) and its implications for human-animal interactions in relation to the Neolithisation process

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Supplementary Material – Methods for: Lipid residue analysis on Swifterbant pottery (c. 5000-3800 cal BC) in the Lower Rhine-Meuse area (the Netherlands) and its implications for human-animal interactions in relation to the Neolithisation process

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Methods

Acidified methanol extraction of lipids

Ceramic was drilled from the interior portion of each vessel (n = 49) and analysed using the established acidified methanol protocol (Craig et al. 2013; Correa-Ascencio and Evershed 2014; Papakosta et al. 2015). In order to eliminate the external contamination to a bare minimum, the outer surface (~0.1 mm) of the sampling area was first removed, using a Dremel drill. Then, the sherds were drilled to a depth of up to 5 mm on the interior surface to produce 1 g of pottery powder. An internal standard (alkane C34:0, 10 μL) was added to 1 g of powdered pottery followed by 4 mL methanol. The suspension was sonicated for 15 minutes, then acidified with concentrated sulphuric acid (H2SO4, 800 μL) and heated for 4 hours at 70°C. Lipids were sequentially extracted with n-hexane (2 mL × 3). The extracts were combined and dried under nitrogen. Finally, an additional internal standard (n-hexatriacontane C36:0, 10 μg) was added to each sample. All samples were analysed by gas chromatography-mass spectrometry (GC-MS) and gas chromatography-combustion isotope ratio mass spectrometry (GC-C-IRMS) in order to obtain molecular and carbon single-compound isotope results. To control for any contamination introduced during the sample preparation, a negative control, containing no ceramic powder, was prepared and analysed with each sample batch.

Gas chromatography-mass spectrometry (GC-MS)

GC-MS analysis was carried out on an Agilent 7890A series GC connected to an Agilent 5975C Inert XL mass-selective detector (Agilent technologies, Cheadle, Cheshire, UK). Splitless injector at 300 °C (1 μL) was used to inject the samples using helium as the carried gas with a constant flow rate at 3 mL/min. The column was inserted into the ion source of the mass spectrometry directly. The MS ionisation energy was 70 eV and spectra scanning window was between m/z 50 and 800. Samples (n = 49) were analysed by using an Agilent DB-5ms (5%phenyl) methylpolysiloxane column (30 m × 0.25 mm × 0.25 μm; J&W Scientific, Folsom, CA, USA). The temperature was set to 50 °C for 2 minutes, followed by a rise of 10 °C per minute up to 350 °C. The temperature was then held at 350 °C for 15
minutes. Compounds were identified by comparing them with the library of mass spectral data and published data.

All samples (n = 49) were also analysed by using a DB-23ms (50%-cyanopropyl)-methylpolysiloxane column (60m x 0.25 mm x 0.25 μm; J&W Scientific, Folsom, CA, USA) in Single Ion Monitoring (SIM) mode to increase the sensitivity for the identification of isoprenoid fatty acids and ω-(o-alkylphenyl) alkanoic acids (APAAs) (Hansel et al. 2004; Cramp et al. 2014). Briefly, the initial temperature profile was 50 ºC for 2 minutes. It was followed by a rise of 4 ºC per minute up to 140 ºC, then 0.5 ºC per minute up to 160 ºC, and then 20 ºC per minute up to 250 ºC. The temperature was then held at 250 ºC for 10 minutes. Scanning then proceeded with the first group of ions (m/z 74, 87, 213, 270), equivalent to 4,8,12-trimethyltridecanoic acid (TMTD) fragmentation; the second group of ions (m/z 74, 87, 88, 101, 312), equivalent to pristanic acid; the third group of ions (m/z 74, 87, 101, 171, 326), equivalent to phytanic acid; and the fourth group of ions (m/z 74, 105, 262, 290, 318, 346), equivalent to ω-(o-alkylphenyl) alkanoic acids of carbon length C16 and C22. Helium was used as the carrier gas with a constant flow rate at 2.4 mL/min. Ion m/z 101 was used to check the relative abundance of two diastereomers of phytanic acids. Quantifications for the peak measurements were calculated by the integration tool on the Agilent Chemstation enhanced data analysis software.

Gas chromatography-combustion isotope ratio mass spectrometry (GC-C-IRMS)
Forty-eight samples which had a lipid concentration over 5 μg g⁻¹ were analysed by GC-C-IRMS in duplicates, following the existing protocol (Craig et al. 2012), in order to measure stable carbon isotope values of methyl palmitate (C₁₆₀) and methyl stearate (C₁₈₀), derived from precursor fatty acids. Samples were analysed by using Delta V Advantage isotope ratio mass spectrometer (Thermo Fisher, Bremen, Germany) linked to a Trace Ultra gas chromatograph (Thermo Fisher) with a GC Isolink II interface (Cu/Ni combustion reactor held at 1000 ºC; Thermo Fisher). All samples were diluted with hexane. Then 1 μL of each sample was injected into a DB5ms fused-silica column (60m × 0.25mm × 0.25μm; J&W Scientific, Folsom, CA, USA). The temperature was fixed at 50 ºC for 0.5 minutes. This was followed by a rise of 25 ºC per minute up to 175 ºC, then 8 ºC per minute up to 325 ºC. The temperature was then held at 325 ºC for 20 minutes. Ultrahigh-purity-grade helium was used as the carrier gas with a constant flow rate at 2 mL/min. Eluted products were ionised in the mass spectrometer by electron ionisation and the ion intensities of m/z 44, 45, and 46 were recorded for automatic computation of ¹³C/¹²C ratio of each peak in the extracts (Heron et al. 2015). Isodat software (version 3.0; Thermo Fisher) was used for the computation, based on the comparison with a standard reference gas (CO₂) with known isotopic composition that was repeatedly measured. The results of the analyses were recorded in ‰ relative to an international standard, Vienna Pee Dee belemnite (VPDB).
N-alkanoic acid ester standards of known isotopic composition (Indiana standard F8-3) were used to determine the instrument accuracy. The mean±standard deviation (SD) values of these n-alkanoic acid ester standards were -29.60±0.21‰ and -23.02±0.29‰ for the methyl ester of C\text{16:0} (reported mean value vs. VPDB -29.90±0.03‰) and C\text{18:0} (reported mean value vs. VPDB -23.24± 0.01‰), respectively. Precision was determined on a laboratory standard mixture injected regularly between samples (28 measurements). The mean±SD values of n-alkanoic acid esters were -31.65±0.27‰ for the methyl ester of C\text{16:0} and -26.01±0.26‰ for the methyl ester of C\text{18:0}. Each sample was measured in replicate (average SD is 0.07‰ for C\text{16:0} and 0.13‰ for C\text{18:0}). Values were also corrected subsequent to analysis to account for the methylation of the carboxyl group that occurs during acid extraction. Corrections were based on comparisons with a standard mixture of C\text{16:0} and C\text{18:0} fatty acids of known isotopic composition processed in each batch under identical conditions.

**Zooarchaeological methods**

Published online datasets (Kooijmans 2001; Kooijmans et al. 2001, and the unpublished Brandwijk dataset provided by DCM Raemaekers) were re-analysed in light of published records (e.g. Zeiler 1997). Primary data from Hazendonk was inaccessible at the time of writing. Relevant specimens in the De Bruin and Brandwijk assemblages were physically re-analysed using the zooarchaeological reference collections at the Groningen Institute of Archaeology (see Çakırlar et al. 2020 for further details). Smallest unit of quantification used in the zooarchaeological datasets and publications is the number of fragments (NF) and corresponding weights in grams. The use of NF calls for caution. In Dutch zooarchaeology, NF equals to the numbers of fragments in an assemblage, regardless of whether they belong to the same specimen or not (specimen \textit{sensu} Stiner 2010). To quantify derived data from NF to estimate the relative taxonomic abundance might lead to even more erroneous results than doing it with NISP (=Number of Identified Specimens), which is usually controlled by predetermined diagnostic portions (\textit{sensu} Davis 1987: 35 or Payne 1972).

**Branched chain fatty acids C\text{15} and C\text{17}**

The relative abundance of branched chain fatty acids (iso- and anteiso-fatty acids) C\text{15br} and C\text{17br} (i15:0, a15:0, i17:0 and a17:0) were separately calculated for all samples with fully aquatic biomarkers (n = 31). This was done based on the results of single ion monitoring (SIM) mode and from ion m/z 87. Then, the ratios of iso- branched chain fatty acids C\text{15} and C\text{17} were calculated based on the formulas below:

\[
C_{15ivstot} = \frac{i15:0}{i15:0 + a15:0}
\]

\[
C_{17ivstot} = \frac{i17:0}{i17:0 + a17:0}
\]
Each sample with fully aquatic biomarkers was compared to the average and standard deviation values of iso ratios of branched chain fatty acids C\textsubscript{15} and C\textsubscript{17} of modern reference data coming from fish and beaver. The values from modern fish are 59 ± 16% for the C\textsubscript{15} and 59 ± 5% for the C\textsubscript{17} branched fatty acids (Hauff and Vetter 2010). As no values for modern beaver adipose or flesh tissue fats were available, novel or previously published modern lipid extracts (Taché and Craig 2015; Courel et al. 2020) from Estonia, Russia and Canada (\textit{Castor fiber} and \textit{Castor canadensis}, n = 10) were analysed according the same procedure that archaeological samples. Values are 19 ± 4% for the C\textsubscript{15} and 35 ± 12% for the C\textsubscript{17} branched fatty acids.

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| ID     | Pre-treatment | Site       | Location            | Culture | Vessel type | Vessel part ** | Decoration | Rim diameter (cm) | Weight (gr) | Wall thickness (mm) | Main tempering material | Surface deposit |
|--------|---------------|------------|---------------------|---------|-------------|----------------|------------|-------------------|-------------|-------------------|--------------------------|-----------------|
| HR-01  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 23                | 79.23       | 10                | grit/grog               |                 |
| HR-02  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot base | no          | -                 | 54.7        | 11                | grit                     |                 |
| HR-03  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 57.54       | 10                | grit                     | yes             |
| HR-04  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 25-30             | 16.09       | 8                 | grit                     | yes             |
| HR-05  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 31.63       | 11                | grit                     | yes             |
| HR-06  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | n/a               | 13.83       | 9                 | grog                      |                 |
| HR-07  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | n/a               | 11.47       | 9                 | grit                     |                 |
| HR-08  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 37.58       | 11                | grit/sand?              | yes             |
| HR-09  | AE            | Polderweg  | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 7.27        | 10                | grog                      |                 |
| HR-10  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 135.31      | 12                | grog                     | yes             |
| HR-11  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 42.86       | 8                 | grog/sand                | yes             |
| HR-12  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 34.20       | 10                | grog/sand                | yes             |
| HR-13  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | 30                | 19.97       | 9                 | sand                      |                 |
| HR-14  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 20-25             | 14.56       | 7                 | grit                      |                 |
| HR-15  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot body/knob | no          | -                 | 35.68       | 11                | grit                      |                 |
| HR-16  | AE            | De Bruin   | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 25-26             | 28.19       | 9                 | grit                      |                 |
| HR-17  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | n/a               | 36.51       | 8                 | grit                      |                 |
| HR-18  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 18                | 40.06       | 7                 | grog                      |                 |
| HR-19  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 20                | 58.37       | 9                 | grit/grog                |                 |
| HR-20  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 15                | 29.03       | 7                 | grog                      |                 |
| HR-21  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | ~25               | 53.52       | 11                | plant material/sand      |                 |
| HR-22  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | 20                | 37.53       | 10                | grog                      |                 |
| HR-23  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot base | no          | -                 | 57.44       | 10                | grit/grog                |                 |
| HR-24  | AE            | De Bruin   | Phase 2             | Inland Waterlogged settlement site | Swifterbant | Cooking pot base | no          | -                 | 115.72      | 10                | grit/grog                |                 |
| HR-25  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot base | no          | -                 | 70.63       | 8                 | plant material            |                 |
| HR-26  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 17-20             | 68.01       | 10                | grit                      | yes             |
| HR-27  | AE            | De Bruin   | Phase 3             | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 33                | 201.9       | 9                 | grit                      | yes             |
| HR-28  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 36                | 251.7       | 11                | grit                      | yes             |
| HR-29  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | 23                | 151.8       | 9                 | grit                      | yes             |
| HR-30  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 19                | 55.3        | 6                 | plant material/grit       |                 |
| BR-01  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 32                | 214.7       | 10                | plant material/grit       | yes             |
| BR-02  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | 40                | 59.9        | 5                 | grit/plant material       | yes             |
| BR-03  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | yes         | -                 | 57.7        | 10                | grit                      | yes             |
| BR-04  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | yes         | -                 | 34.6        | 11                | grit/plant material       | yes             |
| BR-08  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot base | no          | -                 | 56.1        | 7                 | grit                      |                 |
| BR-09  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | yes         | -                 | 21.7        | 8                 | plant material            | yes             |
| BR-10  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 20                | 36          | 10                | mica                     | yes             |
| BR-11  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 30                | 108.7       | 9                 | grit                     | yes             |
| BR-16  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | yes         | -                 | 57          | 10                | plant material/grit       | yes             |
| BR-18  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot body | no          | -                 | 56.1        | 11                | grit/plant material       | yes             |
| BR-20  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | no          | -                 | 21.7        | 8                 | plant material            | yes             |
| BR-22  | AE            | Brandwijk  | L50                 | Inland Waterlogged settlement site | Swifterbant | Cooking pot rim | yes         | 30                | 108.7       | 9                 | grit                     | yes             |
### Supplementary Dataset -1: Sampled pottery information (continues)

| ID     | Sample treatment | Site | Phase | Location                        | Site type                     | Culture | Vessel type | Vessel part ** | Decoration | Rim diameter (cm) | Weight (gr) | Wall thickness (mm) | Main tempering material | Surface deposit (foodcrust) |
|--------|------------------|------|-------|---------------------------------|-------------------------------|---------|-------------|----------------|------------|--------------------|-------------|---------------------|----------------------------|-----------------------------|
| HD-01  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | rim         | yes            | 18         | 29.1               | 11          | grit                |                            | girt                        |
| HD-03  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | body        | yes            | -          | 35.1               | 10          | plant material      |                            |                            |
| HD-05  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | body        | no             | -          | 14                 | 5           | plant material      |                            |                            |
| HD-07  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | body        | yes            | -          | 27                 | 10          | grit                |                            |                            |
| HD-09  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | rim         | yes            | >40        | 20.5               | 8           | grit                |                            |                            |
| HD-11  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | body        | no             | -          | 44.4               | 11          | sand                |                            |                            |
| HD-13  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | rim         | no             | 17         | 35.3               | 6           | grit                |                            |                            |
| HD-15  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | rim         | yes            | 30         | 100.5              | 9           | grog                |                            |                            |
| HD-17  | AE Hazendonk     | 1    | Inland| Waterlogged settlement site     | Swifterbant                  | Cooking pot | rim         | no             | 25-30      | 6.7                | 5           | plant material      |                            |                            |

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Supplementary Dataset -1: Results of organic residue analysis

| sample ID | Sample type | Sampling location | Lipid conc. (μg/g) | ID T1/C2 (C16/C18) | Sample Sampling Lipid conc. (μg/g) | δ13C16:0 | δ13C18:0 | Δ13C | SRR% | APAA C20/C18 ratio | Fully aquatic | Partially aquatic | Other identified lipid markers | C15:1o (%) | C17:1o (%) |
|----------|-------------|------------------|-------------------|---------------------|----------------------------------|----------|----------|------|------|-------------------|---------------|-----------------|--------------------------------|------------|------------|
| HR-01    | Potsherd Internal | 203 1.39 -28.18 -28.66 -0.48 APAA(C16:20), tmtd, pri, phy | 94.9 0.76 | 0.6 x - | - SFA(C15:0-22:0), UFA(C16:1,18:1,11:0), DC(C9:0), br | 0.47 | 0.43 |
| HR-02    | Potsherd Internal | 594 1.03 -33.2 -33.94 -0.74 APAA(C16:18), phy | 96.8 0.66 | 0.46 |
| HR-03    | Potsherd Internal | 58 1.14 -30.03 -30.27 -0.24 APAA(C16:20), tmtd, phy | 93.6 0.59 | 0.56 |
| HR-04    | Potsherd Internal | 45 0.98 -29.79 -30.36 -0.57 APAA(C16:18), tmtd, phy | 69.2 0.62 | 0.42 |
| HR-05    | Potsherd Internal | 791 1.67 -34.46 -34.62 -0.15 APAA(C16:18), tmtd, phy | n/a | 0.53 | 0.38 |
| HR-06    | Potsherd Internal | 117 1.24 -28.71 -29.28 -0.57 APAA(C16:20), tmtd, pri, phy | 86.7 0.53 | 0.38 |
| HR-07    | Potsherd Internal | 101 1.37 -28.22 -29.4 -1.18 APAA(C16:20), phy | n/a | 0.67 | 0.56 |
| HR-08    | Potsherd Internal | 14 1.33 -31.61 -30.76 0.85 APAA(C16:20), phy | 89.9 | 0.67 | 0.56 |
| HR-09    | Potsherd Internal | 13 1.02 -29.8 -30.07 -0.27 APAA(C16:20), phy | 72.4 0.67 | 0.56 |
| HR-10    | Potsherd Internal | 186 1.28 -30.65 -30.2 0.45 APAA(C16:20), phy | 67.8 0.67 | 0.56 |
| HR-11    | Potsherd Internal | 8 0.81 -29.1 -30.1 -1 APAA(C16:20), phy | 71.8 0.67 | 0.56 |
| HR-12    | Potsherd Internal | 22 1.22 -28.14 -29.54 -1.14 APAA(C16:20), phy | 31.7 0.67 | 0.56 |
| HR-13    | Potsherd Internal | 26 1 -28.78 -29.94 -1.16 APAA(C16:20), phy | 51.3 0.67 | 0.56 |
| HR-14    | Potsherd Internal | 15 1.25 -27.76 -29.48 -1.71 APAA(C16:20), phy | 35.8 0.67 | 0.56 |
| HR-15    | Potsherd Internal | 77 1.78 -32.61 -32.49 0.12 APAA(C16:20), tmtd, pri, phy | 86.8 0.67 | 0.56 |
| HR-16    | Potsherd Internal | 414 0.71 -30.59 -32.83 -2.24 APAA(C16:20), tmtd, phy | n/a | 0.67 | 0.56 |
| HR-17    | Potsherd Internal | 42 0.91 -29.32 -30.24 -0.92 APAA(C16:20), tmtd, phy | 94.3 0.67 | 0.56 |
| HR-18    | Potsherd Internal | 28 1 -29.43 -30.34 -0.92 APAA(C16:20), tmtd, phy | 69.8 0.67 | 0.56 |
| HR-19    | Potsherd Internal | 39 1.51 -27.32 -28.62 -1.3 APAA(C16:20), tmtd, phy | 76.4 0.67 | 0.56 |
| HR-20    | Potsherd Internal | 87 1.58 -26.33 -29.6 -3.27 APAA(C16:20), tmtd, phy | 72 0.67 | 0.56 |
| HR-21    | Potsherd Internal | 25 1.14 -28.4 -29.63 -1.23 APAA(C16:20), tmtd, phy | 45.2 0.67 | 0.56 |
| HR-22    | Potsherd Internal | 42 1.68 -31.39 -30.95 0.44 APAA(C16:20), tmtd, phy | 93.4 0.67 | 0.56 |
| HR-23    | Potsherd Internal | 131 2.63 -30.32 -30.35 -0.12 APAA(C16:20), tmtd, pri, phy | 69.1 0.67 | 0.56 |
| HR-24    | Potsherd Internal | 236 2.35 -29.91 -29.4 0.52 APAA(C16:20), tmtd, phy | 83.6 0.67 | 0.56 |
| HR-25    | Potsherd Internal | 163 1.32 -31.95 -31.63 0.32 APAA(C16:20), tmtd, pri, phy | 78.9 0.67 | 0.56 |
| HR-26    | Potsherd Internal | 153 2.71 -32.52 -31.14 1.38 APAA(C16:20), tmtd, phy | 84 0.67 | 0.56 |
| HR-27    | Potsherd Internal | 1.34 1.21 -30.39 -29.8 0.59 APAA(C16:20), tmtd, phy | 90 0.67 | 0.56 |
| HR-28    | Potsherd Internal | 910 1.06 -26.2 -26.02 0.17 APAA(C16:20), tmtd, pri, phy | 59.4 0.67 | 0.56 |
| HR-29    | Potsherd Internal | 406 1.04 -31.47 -36.38 -4.9 APAA(C16:20), tmtd, pri, phy | 65.3 0.67 | 0.56 |
| HR-30    | Potsherd Internal | 847 1.26 -31.6 -30.31 1.29 APAA(C16:20), tmtd, pri, phy | 93.6 0.67 | 0.56 |
| HR-31    | Potsherd Internal | 146 1.59 -31.32 -29.78 1.54 APAA(C16:20), tmtd, pri, phy | 88.6 0.67 | 0.56 |
| HR-32    | Potsherd Internal | 156 2.13 -31.83 -30.81 1.02 APAA(C16:20), tmtd, phy | 92.7 0.67 | 0.56 |
| HR-33    | Potsherd Internal | 118 2.63 -31.71 -30.83 0.89 APAA(C16:20), tmtd, phy | 52.9 0.67 | 0.56 |
| HR-34    | Potsherd Internal | 264 2.14 -32.53 -32.35 0.18 APAA(C16:20), tmtd, phy | 69.1 0.67 | 0.56 |
| HR-35    | Potsherd Internal | 130 1.9 -24.77 -25.9 -1.13 APAA(C16:20), tmtd, phy | 69.4 0.67 | 0.56 |
| HR-36    | Potsherd Internal | 160 1.83 -33 -33.03 -0.03 APAA(C16:20), tmtd, phy | 53.5 0.67 | 0.56 |
| HR-37    | Potsherd Internal | 617 0.83 -30.93 -29.35 1.58 APAA(C16:20), tmtd, phy | 97 0.67 | 0.56 |
| HR-38    | Potsherd Internal | 397 1.36 -30.95 -31.67 0.07 APAA(C16:20), tmtd, pri, phy | 91.2 0.67 | 0.56 |
| HR-39    | Potsherd Internal | 114 1.65 -26.49 -26.54 -0.05 APAA(C16:20), tmtd, phy | 61.8 0.67 | 0.56 |
| Sample ID | Sample type | Location | Lipid conc. (μg/g) | SRR% | Aquatic biomarkers | APAA C20/C18 ratio | Fully aquatic | Partially aquatic | Other identified lipid markers | C15iso (%) | C17iso (%) |
|-----------|-------------|----------|-------------------|------|-------------------|-------------------|--------------|------------------|-------------------------------|------------|------------|
| HD-01     | Potsherd    | Internal | 90                | 32.8 | APAA(C16-18), tmtd, phy | -                 | x            | -                | SFA(C14:0-26:0), UFA(C16:1, 17:1, 18:1), br, chol | 0.57       | 0.64       |
| HD-03     | Potsherd    | Internal | 36                | 79.9 | APAA(C10-22), tmtd, phy | 0.33             | x            | -                | SFA(C13:0-28:0), DC(C9:0), br, chol, tr | 0.63       | 0.63       |
| HD-05     | Potsherd    | Internal | 92                | 41.3 | APAA(C10-22), tmtd, phy | 0.61             | x            | -                | SFA(C14:0-24:0), br | 0.39       | 0.35       |
| HD-07     | Potsherd    | Internal | 104               | 28.4 | APAA(C16-18), tmtd, phy | 0.61             | x            | -                | SFA(C14:0-24:0), br | 0.55       | 0.65       |
| HD-09     | Potsherd    | Internal | 245               | 30.4 | APAA(C16-18), phy     | 0.68             | x            | -                | SFA(C12:0-22:0), UFA(C20:1), DC(C9:0), br | 0.55       | 0.65       |

(Cn:x) - carboxilic acids with carbon length n and number of unsaturations x, SFA – saturated fatty acid, UFA – unsaturated fatty acids, DC - α,ω-dicarboxylic acids, APAA - ω-(o-alkylphenyl) alkanoic acids, br - branched chain acids, tmtd - 4,8,12-trimethyltridecanoic acid, pri – pristanic acid, phy – phytanic acid with the percentage contribution of SRR diastereomer in total phytanic acid, chol - cholesterol or derivatives.

**All the sampled vessel fragments in this study represent individual vessels However, they do not represent all the individual vessels identified at each site.**
**Supplementary Dataset -2: Faunal data – Mammals, Birds, and Fish**

| Mammals | Class/order/family | Species | Polderweg 0 | Polderweg 1 | Polderweg 1/2 | Polderweg 2 | De Bruin 1 | De Bruin 2 | De Bruin 3 | Brandwijk L30 | Brandwijk L50 | Brandwijk L60 | Hazendonk 1 & 2 |
|----------|--------------------|---------|-------------|-------------|--------------|------------|-----------|-----------|-----------|--------------|-------------|-------------|-----------------|
| Beaver   | Castoridae         | Castor fiber | 15        | 1174       | 1443        | 1942       | 1070      | 8083      | 2942       | 815          | 600          |             |                 |
| Otter    | Mustelidae         | Lutra lutra | 18        | 1159       | 1210        | 2626       | 4444      | 45111     | 11811      | 11622        | 51051       |             |                 |
| Common seal | Phocidae   | Phoca vitulina | 1        | 6          |             |           |           |           |           |             |             |             |                 |
| Gray seal | Phocidae         | Halichoerus grypus | 3        | 2          | 71          | 1          |           |           |           |             |             |             |                 |
| Elk (without antler) | Cervidae | Alces alces | 1        | 12         | 3           | 1          |           |           |           |             |             |             |                 |
| Red deer (without antler) | Cervidae | Cervus elaphus | 1        | 92         | 2           | 12          | 6512      | 1812      | 2412       | 1712         | 3121        |             |                 |
| Roe deer (without antler) | Cervidae | Capreolus capreolus | 14      | 1          | 1           | 17          | 412       |           |           |             |             |             |                 |
| Deer (with antler) | Cervidae | -           | 8         | 71          | 19          |           |           |           |           |             |             |             |                 |
| Aurochs | Bovidae           | Bos primigenius | 9        | 1           | 8           | 2          |           |           |           |             |             |             |                 |
| Cattle / Aurochs | Bovidae | Bos taurus / Bos primigenius | 1        | 15         | 6           | 3          | 2515      |           |           |             |             |             |                 |
| Wild boar | Suidae            | Sus scrofa | 5         | 977        | 6310        | 10101      | 6512      |           |           |             |             |             |                 |
| Pig / Wild boar | Suidae | Sus domesticus / Sus scrofa | 23    | 136        | 5311        | 1           | 2212      | 1712      |           |             |             |             |                 |
| Pig     | Suidae            | Sus domesticus | 1        | 3          |             |           |           |           |           |             |             |             |                 |
| Sheep/goat | Bovidae         | Ovis aries / Capra hircus | 2        | 11         | 2           | 10         | 11        |           |           |             |             |             |                 |
| Dog     | Canidae           | Canis familiaris | 1        | 312        | 2315        | 15          | 2612      | 2812      | 312        |             |             |             |                 |
| Other   |                  |            | 3         | 60         | 412         | 1           | 2310      | 5110      | 1101       | 812          | 2012        |             |                 |

**Mammals (unidentified)**

|                  |                    |                    | Polderweg 0 | Polderweg 1 | Polderweg 1/2 | Polderweg 2 | De Bruin 1 | De Bruin 2 | De Bruin 3 | Brandwijk L30 | Brandwijk L50 | Brandwijk L60 | Hazendonk 1 & 2 |
|------------------|--------------------|--------------------|-------------|-------------|--------------|------------|-----------|-----------|-----------|--------------|-------------|-------------|-----------------|
| Small mammal     |                    |                    | 38          | 6663        | 775157      | 291157     | 36051205 |           |           |             |             |             |                 |
| Medium-sized mammal |                |                    | 3           | 778         | 785         | 5170       | 551210    |           |           |             |             |             |                 |
| Medium to large mammal |            |                    | 5           | 241         | 178         | 56289      | 63289     |           |           |             |             |             |                 |
| Mammal, indet.   |                    |                    | 330         | 385555      | 3422351     | 11876325   | 236324     | 218136    | 176136    |             |             |             |                 |

*In Brandwijk: just 'indet' (not clear if only mammal)*
| Class/order/family | Species | >5500 cal BC | 5500-5300 cal BC | 5150-5050 cal BC | 5050-4950 cal BC | 5100-4800 cal BC | 4700-4450 cal BC | 4610-4550 cal BC | 4220-3940 cal BC | 3940-3820 cal BC | 4020-3960 cal BC | 5100-4000 cal BC | 6700-6400 cal BC | 6200-3940 cal BC | 3940-3520 cal BC | 4020-3960 cal BC |
|--------------------|---------|-------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Birds (identified) |         |             |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Mute swan          | Cygnus olor | 10           | 1               | 2               | 3               | 5               | 1               |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Bewick's swan      | Cygnus b. | 2            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Whooper swan       | Cygnus cygnus | 2          |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Mute swan/Whooper swan | Cygnus olor / Cygnus cygnus | 1 | 27 | 1 | 1 | 7 | 30 | 1 | 3 |                 |                 |                 |                 |                 |                 |                 |                 |
| Swans              | Cygnus sp. | 1            |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| cf Swans           | Cygnus sp. | 1            | 1       |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Bean goose         | Anser fabalis | 4         |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Greylag goose      | Anser anser | 1            | 2       |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Grey geese         | Anser sp. | 1            | 2       |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Grey geese / Black geese | Anser sp. / Branta sp. | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Shelduck           | Tadorna tadorna | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Mallard            | Anas platyrhynchos | 1 | 165 | 21 | 12 | 4 | 120 | 39 | 2 | 3 |                 |                 |                 |                 |                 |                 |                 |
| Northern shoveler  | Anas clypeata | 5 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Wigeon             | Anas penelope | 2 | 2       | 2       | 2 | 7 | 4 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common teal        | Anas crecca | 4            | 3       | 1               | 1               |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common teal / Garganey | Anas crecca / Anas querquedula | 5 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Pochard            | Aythya ferina | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Tufted duck        | Aythya fuligula | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Diving ducks       | Aythya sp. | 1            | 41      | 3               | 1               | 27 | 10 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Goosander          | Mergus merganser | 25 |                 | 3               |                 |                 | 2 | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Long-tailed duck   | Clangula hyemalis | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common goldeneye   | Bucephala clangula | 3 | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Ducks              | Anas sp. / Aythya sp. | 54 | 21 | 1 | 1 | 61 | 36 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Ducks              | Mergus sp. / Bucephala sp. |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Coot               | Fulica atra | 9            | 1       |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common moorhen     | Gallinula chloropus | 7 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Little crane       | Porana pora | 2 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Water rail         | Rallus aquaticus | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Rails              | Rallus | 2 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common crane       | Grus | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Little grebe       | Tachybaptus ruficollis | 5 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Great bittern      | Botaurus stellaris | 7 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Grey heron         | Ardea cinerea | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Purple heron       | Ardea purpurea | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Herons             | Ardea sp. | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Red-throated diver | Gavia stellata | 9 | 1 | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Cormorant          | Phalacrocorax | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Plovers            | Charadrius sp. | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Eurasian woodcock  | Scolopax rusticola | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Great spotted woodpecker | Dendrocopos major | 5 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Thrushes           | Turdus sp. | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common reed bunting | Emberiza schoeniclus | 2 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Small songbird     | Passeriformes | - |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Eurasian eagle-owl | Buho budo | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Northern goshawk   | Accipiter gentilis | 1 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Eurasian sparrowhawk | Accipiter nisus | 3 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| White-tailed eagle | Haliaeetus albicilla | 1 | 30 | 1 | 1 | 9 | 2 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Common buzzard     | Buto buto | 3 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Accipitricks       | Accipiter | 2 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Birds (unidentified) |         |             |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |                 |
| Indet.             |         | 5 | 139 | 21 | 17 | 187 | 191 | 3 | 1 | 3 |                 |                 |                 |                 |                 |                 |

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| Fish (identified) | Class/order/family | Species          | Scales indicated; totals are without scales | Including scales, but amount not in test/table |
|---------------------|--------------------|------------------|---------------------------------------------|-----------------------------------------------|
| **Freshwater species** |                    |                  |                                             |                                               |
| Bream               | Cyprinidae         | Abramis brama    | 235                                         | 5878                                          | 18                                          | 4                                          | 287                                          | 349                                          | 193                                          | 2                                          |
| Silver bream        | Cyprinidae         | Abramis hoberauda| 3                                           | 8                                             | 2                                           |                                             |                                             |                                              |                                              |                                             |
| Chub                | Cyprinidae         | Squallus cephalus| 1                                           | 36                                            |                                             |                                             |                                             |                                              |                                              |                                             |
| Ide                 | Cyprinidae         | Leuciscus idus   | 34                                          | 483                                           | 7                                           | 12                                          | 63                                           |                                              |                                              |                                              |
| Roach               | Cyprinidae         | Rutillus rutulus | 1                                           | 23                                            |                                             |                                             |                                              |                                              |                                              |                                              |
| Rudd                | Cyprinidae         | Rutillus erythrophthalmus | 1 | 22                                           |                                             |                                             |                                              |                                              |                                              |                                              |
| Trench              | Cyprinidae         | Tinca tinca      | 1                                           | 20                                            |                                             |                                              |                                              |                                              |                                              |                                              |
| Chub / Rudd         | Cyprinidae         | Squallus cephalus / Rutillus erythrophthalmus | 1 | 20                                           |                                             |                                              |                                              |                                              |                                              |                                              |
| Cyprinids (including squama) | Cyprinidae | -                | 148                                         | 3087                                          | 20                                          | 9                                           | 288                                          | 581                                          | 159                                          |                                              |
| Cyprinids (without squama) | Cyprinidae | -                | 148                                         | 3086                                          | 20                                          | 9                                           |                                              |                                              |                                              |                                              |
| Pike                | Esocidae           | Esos lucius      | 200                                         | 8930                                          | 106                                         | 81                                          | 559                                          | 1928                                         | 1031                                         | 2                                           | 2                                           | 7                                           |
| Perch (including squama) | Percidae | Perca fluviatilis | 45                                         | 835                                           | 4                                           | 9                                           | 210                                          | 648                                          | 148                                          |                                              |                                              |                                              |
| Perch (without squama) | Percidae | Perca fluviatilis | 41                                         | 828                                           | 4                                           | 9                                           |                                              |                                              |                                              |                                              |                                              |                                              |
| Eel                 | Anguillidae        | Anguilla anguilla| 15                                          | 1                                             |                                             |                                             |                                              |                                              |                                              |                                              |                                              |                                             |
| Catfish             | Siluridae          | Silus glanis     | 44                                          | 2                                             |                                             | 13                                          | 38                                          | 10                                           |                                              |                                              |                                              |
| **Migratory species** |                    |                  |                                             |                                               |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| European sturgeon   | Acipenserida       | Acipenser sturio | 17                                          | 1                                             | 1                                           | 32                                          | 118                                         | 16                                           | 1                                            |                                              |                                              |                                              |
| Herring             | Salmonidae         | Coregonus oxyrincaha | 76 | 153                                          |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| Whitefish (fresh and migrates) | Salmonidae | Coregonus sp. | 1                                           | 4                                             | 1                                           |                                             |                                              |                                              |                                              |                                              |                                              |                                              |
| Salmon              | Salmonidae         | Salmo salar      | 8                                           | 5                                             | 1                                           | 29                                          |                                              |                                              |                                              |                                              |                                              |                                              |
| Salmon / Sea trout  | Salmonidae         | Salmo salar / Salmo trutta | 1 | 29                                           |                                             |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| Salmonids           | Salmonidae         | -               |                                             |                                               |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| Allis shad          | Clupeidae          | Alosa alosa      | 69                                          | 49                                           | 1                                           |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| Twaite shad         | Clupeidae          | Alosa fallax     | 1                                           |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| **Marine species**  |                    |                  |                                             |                                               |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |
| Mullets             | Mugilidae          | -               |                                             |                                               |                                              |                                              |                                              |                                              |                                              |                                              |                                              |                                              |

**Fish (unidentified)**

| Indet. (including squama) | 630 | 36743 | 171 | 148 | 1897 | 3094 | 2402 |
|----------------------------|-----|-------|-----|-----|------|------|------|
| Indet. (without squama)    | 629 | 36288 | 171 | 148 | 1    |      |      |

For fish remains for Hazendonk; Only multiple phase totals known (in Brinkhuizen 1979)

References used to gather data: Zeiler 1997, Table 2, Table 3; Raemaekers 1999, Table 3, 3.49; Overssteegen, J.F. et al. 2001, Table 8.7; Van Wijngaarden-Bakker et al. 2001, Table 8.9; Beerenhout 2001a, Table 9.3; Beerenhout 2001b, Table 9.11; Amkreutz 2013, Fig.7.4, Fig.7.4b; Çakırlar et al. 2019, SM Table 3; Çakırlar et al. 2020, Table 13.3

-All counts in NF (Dutch way of counting all fragments): Not to be confused by NISP

-Changes in Brandwijk data: this study and Çakırlar et al. 2020
Supplementary Dataset -2: Table 1: Site distribution of average Sus sp. fragment weight (in grams)
## Supplementary Material Dataset-3

| Common name | Taxa         | Sample type | Period  | Provenience       | C15iso (%) | C17iso (%) |
|-------------|--------------|-------------|---------|-------------------|------------|------------|
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.19       | 0.31       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.22       | 0.36       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.23       | 0.34       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.22       | 0.32       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.18       | 0.38       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.18       | 0.27       |
| Beaver      | Castor fiber | tissue      | Modern  | Estonia           | 0.22       | 0.32       |
| Beaver      | Castor fiber | tissue      | Modern  | Russia - Middle Don | 0.18     | 0.38       |
| castor      | Castor fiber | tissue      | Modern  | Russia - Upper Volga | 0.22     | 0.66       |
| Beaver      | Castor canadensis | Soft tissue | Modern  | Canada           | 0.09       | 0.19       |
