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Neolithic Human Diet

Based on Studies of Coprolites from the Swifterbant Culture Sites, the Netherlands

Lucy Kubiak-Martens and Marjolein van der Linden (eds)

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Neolithic Human Diet Based on Studies of Coprolites from the Swifterbant Culture Sites, the Netherlands
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Preface

The archaeological study of food is a growing area of interest. Coprolites hold an important key to the reconstruction of past human subsistence and the value of coprolite data has therefore increased over the last decades. The coprolites provide information on diet and health. Some authors refer to coprolites as the missing links in our knowledge of the prehistoric diet as they offer direct evidence for dietary diversity and the preparation and consumption of food. The study of coprolites provides a unique opportunity to reconstruct the most complete spectrum of the foods that were consumed, both as cooked meals and plant foods that were eaten raw as green vegetables. Soft plant tissues are rarely preserved in other types of archaeological finds. Even though leaf or stem tissues of herbaceous plants are occasionally found in charred food residues encrusted on ceramics, and as such indicate that some green vegetables were cooked, a large variety of plants and their green parts would have been eaten raw.

Commissioned by the Cultural Heritage Agency of the Netherlands (RCE), BIAX Consult Biological Archaeology & Landscape Reconstruction led the project 'Neolithic human diet' based on studies of human coprolites from the Swifterbant sites excavated before 2007. A group of senior researchers from BIAX Consult, Delft University of Technology and ArchaeoBone (Netherlands), Newcastle University and Durham University (United Kingdom), and Universitat Autònoma de Barcelona (Spain) worked together, incorporating their research methods.

Our focus for this study was on coprolites from three sites located in two research areas. One area is the Lower Rhine-Meuse delta in the western part of the Netherlands, with the Hardinxveld-Giessendam De Bruin site dating around 5500–4450 cal BC (Late Mesolithic – Early Neolithic). The other area is in the province of Flevoland, in the north-central part of the Netherlands. Here, two sites were of particular interest, Swifterbant-S3 and -S4, dated to the Early Neolithic, the classic phase of the Swifterbant Culture around 4300–4000 cal BC.

The main research questions of this project were regarded with the dietary diversity and preparation of food in the Swifterbant tradition, with attention to both plant and animal components. The evidence for the consumption of plant foods in general, and cereals in particular, was of great interest. Also of much concern were the health conditions of the Swifterbant populations.

The present publication provides the most comprehensive coprolite study ever conducted from archaeological sites in the Netherlands. The results of this multidisciplinary project constitute an extensive source of data for prehistoric dietary diversity and health and provide new insights into the Swifterbant tradition and food culture.

The editors (Lucy Kubiak-Martens and Marjolein van der Linden)

Summary

The project 'Neolithic Human Diet Based on Studies of Coprolites from the Swifterbant Culture Sites in the Netherlands' was one in a series of studies referred to as Pre-Malta projects. The aim of the project was to assess the diet and health of the Swifterbant Culture populations through the analysis of coprolites from sites excavated before 2007. Four sites were selected as they provided preservation of coprolites: Hardinxveld-Giessendam De Bruin, dated to c. 5500 to 4450 cal BC, the Swifterbant-S3 and -S4 sites, dated to c. 4300-4000 cal BC, and the Emmeloord-J78-91, dated to c. 2400-2100 cal BC.

A group of seven specialists from universities and commercial companies worked together, each contributing distinct data sets to the project. Multiple proxies were combined, including faecal steroids, micro-CT scans, SEM images, animal bone remains, phytoliths, pollen, intestinal parasites and starch granules.

In this project the primary focus was on human coprolites. Human faecal remains, however, are often difficult to identify with certainty. The method which was used in this study to distinguish human from animal coprolites was gas chromatography-mass spectrometry (GC-MS). Unfortunately, the identification of the coprolitic source organisms was limited by low concentrations of faecal biomarkers, which either precluded source identification or presented multiple possible source organisms. Humans, pigs and carnivores (likely dogs) were the dominant producer organisms of the confirmed coprolites, accounting for at least eleven of the 25 GC-MS-examined coprolites.

Based on the results of the initial GC-MS faecal lipid biomarker assessment, 13 coprolites were initially subjected to micro-CT scan and Scanning Electron Microscope (SEM) analyses, including six coprolites of human origin (S3-2, S3-4, S3-10, S3-20, S3-28 and S4-1), two of likely-human origin (S3-15 and S4-4), three coprolites of animal origin, including two pigs (Hardinxveld-Giessendam 19952 and S3-18) and one ruminant (S3-5), as well as two coprolites of unknown source organism (S3-11 and S3-13). Additional three coprolites were added later to the micro-CT scan and SEM analyses.

The micro-CT scans indicated the dominant presence of fish remains in all 16 of the analysed coprolites, indicating that fish were frequently eaten, perhaps on a daily basis. Pike, perch and cyprinids (sometimes combined) formed part of the diet. Fish bone remains included vertebrae, fish scales and head bones (including teeth). In all cases, the remains came from very small individuals (mainly pike and cyprinid fish) of no more than 10 cm long. This, all together, would suggest that the whole fish was eaten. It was probably cooked in pots, which would have softened the bones.

Some of the research questions of the project were related to the consumption of cereals. The SEM analysis demonstrated a cereal component in five coprolites (S3-2, S3-4, S3-5, S3-28 and S4-1). The cereal tissue embedded in the matrices of these coprolites was assigned to the epidermal tissue of emmer chaff, which most likely derived from light chaff (often referred to as the husk). The evidence for the cereal presence is also found in phytolith remains (S3-4, S3-5, S3-10, S3-13, S3-15, S3-18 and S3-20). The phytoliths embedded in coprolite matrices were exceptionally well preserved and, in contrast to most coprolites, were present in large quantities. The phytoliths indicated the presence of cereal husks, including *Triticum* (likely emmer) and *Hordeum* (likely naked barley). The evidence for the consumption of cereals was also detected during pollen and intestinal parasite analysis. On the microscopic slides, in four coprolites cereal pollen was encountered (S3-4, S3-10, S3-28 and S4-1) and emmer chaff epidermal particles was often observed (S3-4, S3-11, S3-18, S3-28 and S4-1). Fragments of grain pericarp tissue (bran) from *Triticum* (likely emmer; in S3-20) and likely *Hordeum* (in S3-10) were also preserved. The grain pericarp tissues embedded in coprolite matrices offer the best possible evidence for the consumption of cereals. Even though the number of remains derived from cereals was relatively low, they were present in ten of the studied coprolites (from Swifterbant-S3 and -S4). This would suggest that cereals would have been consumed quite often but were combined with other foods.

The herbaceous leaf/stem tissues found in many of the coprolites suggest that a variety of 'green vegetables' would have been eaten by humans - and likely also by their domestic animals. Knotgrass leaves would have likely been used by humans as greens/leaf vegetables. The charred epidermal tissue of likely *Allium* bulb

found in one of the human coprolites suggests that some species of wild onion or garlic would have been gathered for its bulbs and perhaps for its greens. The leaves of mistletoe would have been used as animal (pig) fodder. In many coprolites, vascular tissue (often charred), sponge parenchyma (probably of the leaf or stem tissues), and periderm (probably of roots and tubers) were found, confirming that vegetative plant parts were indeed on the menu of the people of the Swifterbant Culture.

Various seeds, fruits and berries would have also been used for food. Seeds of water-lily found in great abundance in two Swifterbant-S3 coprolites, accompanied by crab apple in a few other coprolites, can likely be interpreted as an element of the Swifterbant diet which goes back to a Mesolithic culinary tradition.

Pollen found in the coprolite matrices may have reached the human intestines by inhalation or in food or drinks, or as medicine. Many plant taxa present in the pollen and intestinal parasite samples could have been used for food or drink, but also for their medicinal properties. One of the examples is marsh mallow (*Althaea officinalis*). The leaves and roots of marsh mallow are edible, whereas the flowers and other plant parts can be used in herbal drinks.

The level of infestation with intestinal parasites appears to have been rather high on the Swifterbant settlement and one would wonder whether self-medication or other ways of using plant remedies was practised. Interestingly, although only one coprolite from Hardinxveld-Giessendam De Bruin was studied for the presence of intestinal parasites, it revealed a different helminth composition than those present in the Swifterbant-S3 and -S4 coprolites. In Hardinxveld-Giessendam De Bruin, only eggs of trematoda, possibly Fascioliidae (flukes), are present. In Swifterbant helminth eggs of Diphyllobothriidae (including *Diphyllobothrium*, fish tapeworms) and Opisthorchiidae (flukes) and *Dioctophyma* (giant kidney worm) are present. In almost all of the coprolites from Swifterbant-S3 and -S4, helminth eggs are present which are probably from a human host (*Trichuris trichiura*). *Trichuris* is a good indicator for faeces in the soil. In Swifterbant, the frequent presence of *Trichuris* may indicate the fouling of the soil with faeces, which implies the long-term presence of humans (and animals) at one site.

Although this project aimed to reconstruct the Neolithic human diet based on human coprolites, the fact that we were working with a mixed coprolite assemblage means that our contribution may be regarded as the reconstruction of the community diet. It seems that clarifying the diet on the level of individual species (humans in particular) might be challenging, if not impossible, particularly at archaeological sites such as Hardinxveld-Giessendam De Bruin and the Swifterbant-S3 and -S4 sites, where people were living together with their dogs (and pigs, nearby), and likely all shared a similar diet. Although it seems like activity areas were kept clean, the hygienic conditions at the settlements must have been poor since the health of both humans and their animals was affected by multiple intestinal parasites infections.

Samenvatting

Het project '*Neolithic human diet based on studies of coprolites from the Swifterbant sites*' (Het neolithisch menselijk eetpatroon gebaseerd op studies van coprolieten van de Swifterbant vindplaatsen) was een van de onderzoeken die in opdracht van de Rijksdienst voor het Cultureel Erfgoed zijn uitgevoerd. Het doel van dit project was het vaststellen van het eetpatroon en de gezondheid van de mensen van de Swifterbantcultuurdoor middel van het onderzoeken van coprolieten van archeologische vindplaatsen die voor 2007 waren opgegraven. Vier vindplaatsen werden geselecteerd voor dit onderzoek omdat daar coprolieten bewaard waren gebleven: Hardinxveld-Giessendam De Bruin, gedateerd tussen 5500 tot 4450 v. Chr.,; de Swifterbant-S3 en S4 vindplaatsen, daterend tussen 4300-4000 v. Chr.; en vindplaats Emmeloord-J78-91, daterend tussen 2400-2100 v. Chr.

Binnen het project werkten een groep van zeven specialisten van diverse universiteiten en bedrijven werkten samen, en voerden diverse interdisciplinaire onderzoeksmethoden uit. Zo werd een gecombineerd onderzoek aan meerdere *proxies* uitgevoerd aan fecale steroïden, dierlijke botresten, fytolieten, pollen en andere microfossielen, darmparasieten, en zetmeel middels chemisch onderzoek, microscopisch onderzoek, micro CT-scans en rasterelektronenmicroscopie (SEM-onderzoek).

De primaire focus van dit project lag op menselijke coprolieten. Resten van menselijke feces zijn echter moeilijk met zekerheid te determineren. De methode die in dit project is gebruikt berust op de techniek gaschromatografie-massaspectrometrie (GC-MS). Helaas werd het achterhalen van de afkomst van de coprolieten bemoeilijkt vanwege de lage concentratie fecale biomarkers (lipiden en galzuren). Dit zorgde ervoor dat het vaststellen van een afkomst onmogelijk was of meerdere opties mogelijk waren. Wat toch duidelijk werd van de fecale biomoleculaire analyse was dat zowel menselijk als dierlijke coprolieten vertegenwoordigd waren in de te bestuderen coprolieten. Mensen, varkens en carnivoren (waarschijnlijk honden) zijn hierbij de meest voorkomende afkomsten van de coprolieten. Zo konvoor elf van de 25 coprolieten die met de GC-MS-techniek zijn onderzocht kon de afkomst worden vastgesteld.

In eerste instantie zijn op basis van de eerste resultaten van het GC-MS-onderzoek dertien coprolieten geselecteerd voor micro CT-scan en SEM-onderzoek. Het gaat om zes coprolieten waarvan gedacht werd dat deze van menselijke origine waren (S3-2, S3-4, S3-10, S3-20, S3-28, S4-1), twee waarschijnlijk vanmenselijke origine (S3-15, S4-4), drie coprolieten van dierlijke oorsprong waaronder twee van varken (Hardinxveld 19952, S3-18) en één van een herkauwer (S3-5), en twee coprolieten van onbekende oorsprong (S3-11 en S3-13). Drie coprolieten werden later alsnog toegevoegd aan de micro CT-scan en het SEM-onderzoek.

De micro-CT scans lieten zien dat er visbotresten aanwezig waren in alle zestien coprolieten (in twee gevallen gingen deze visbotten samen met zoogdierbotresten en in een geval met een stukje vogelbot). Het grote aantal visbotresten doet vermoeden dat vis vaak werd gegeten, misschien zelfs dagelijks. Uit de botresten kon afgeleid worden dat snoek, baars en vissen uit de karperfamilie op het menu stonden. De visresten bestonden uit wervels, schubben en botjes uit de kop (inclusief tanden). In alle gevallen waren de botresten afkomstig van kleine individuen (voornamelijk snoek maar ook van de karperfamilie) die niet groter dan 10 cm lang waren. Al deze resten samen doen vermoeden dat de gehele vis werd gegeten. De vis werd mogelijk gekookt in potten, wat de botten zacht zal hebben gemaakt.

Een aantal van de onderzoeksvragen had betrekking op de consumptie van granen. Het SEM-onderzoek liet zien dat in vijf coprolieten (S3-2, S3-4, S3-5, S3-28 en S4-1) het plantaardig weefsel van de granen dat in de coprolieten was ingebedtoegeschreven kon worden aan kaf van emmer. Het kaf was waarschijnlijk afkomstig van licht kaf (vaak de schil genoemd), waaronder lemma's, paleae en vliesjes. Het lijkt er op dat een deel van het fijne kaf van emmer het pellen van het graan heeft doorstaan, en nog aan de graankorrel heeft vastgezeten toen het de kookpot in ging.

Het bewijs voor de aanwezigheid van granen in de voeding is ook via fytolieten aangetoond (bij coprolieten S3-4, S3-5, S3-10, S3-13, S3-15, S3-18 en S3-20). De fytolieten die in de coprolieten ingebed waren, zijn uitzonderlijk goed geconserveerd en waren in hoge aantallen aanwezig, wat niet altijd het geval is in andere coprolieten. Het fytolietenonderzoek heeft

aangetoond dat zowel de graanschillen van tarwe (vermoedelijk emmertarwe) en gerst (vermoedelijk naakte gerst) aanwezig waren. Bewijs voor de consumptie van granen is ook geleverd via het pollen- en darmparasietenonderzoek, waarbij op de microscopische preparaten ook andere microfossielen en plantenresten zijn aangetroffen dan pollen en darmparasieteneieren. In vier coprolieten is stuifmeel van granen gevonden (S3-4, S3 -10, S3-28 en S4-1). Bij het microscopisch onderzoek aan de overige resten werden verkoolde kafresten van (aannemelijk) emmertarwe met regelmaat aangetroffen (S3-4, S3-11, S3-18, S3-28 en S4-1). In sommige coprolieten zijn tevens resten van de zemelen (fragmenten van graan pericarp) van tarwe (vermoedelijk emmertarwe in S3-20) en van vermoedelijk gerst gevonden (in S3-10). De fragmenten van pericarp (de buitenwand van de graankorrel) zijn ingebed in de coprolieten en is het best mogelijke bewijs voor de consumptie van granen.

De plantaardige blad- en stengelweefsels die zijn aangetroffen in het SEM-onderzoek alsook in het microscopische onderzoek aan pollen en andere microfossielen, suggereren dat een grote variatie aan kruidachtige planten en hun groenten zijn gegeten door mensen – en ook door hun gedomesticeerde dieren. De bladeren van gewoon varkensgras kunnen door mensen gebruikt zijn als (blad)groenten. De bladeren, en mogelijk ook de gehele jonge planten, van gewoon varkensgras zijn waarschijnlijk ook gegeten door gedomesticeerde dieren. De aanwezigheid van epidermisweefsel van de bol van vermoedelijk look in een van de menselijke coprolieten, suggereert dat een soort wilde ui of knoflook werd verzameld voor zijn eetbare bollen en mogelijk de eetbare groene bladeren. De bladeren van maretak zijn waarschijnlijk gebruikt als diervoeding (bijvoorbeeld voor varkens), mogelijk als wintervoeding. In veel coprolieten zijn plantaardige resten gevonden van o.a. vaatbundels (vaak verkoold), sponsparenchym (waarschijnlijk van blad- of stengelweefsel), en periderm (waarschijnlijk van wortels en knollen), die tevens laten zien dat plantaardig voedsel zeker op het Swifterbant menu stond.

Diverse zaden, vruchten en bessen zullen ook op het Swifterbant menu hebben gestaan. De zaden van waterlelie zijn in grote hoeveelheden in twee van de Swifterbant-S3 coprolieten gevonden. In sommige coprolieten kwamen deze samen voor met zaden van appel. De aanwezigheid van deze verzamelde eetbare planten kan gezien worden als een mesolithisch element in de culinaire traditie van de Swifterbant cultuur.

Pollen in coprolieten kan de menselijke ingewanden bereikt hebben via inhalatie of door inname met voedsel, drinken of als medicijn. In alle bestudeerde coprolieten zijn veel planten gevonden waarvan delen gebruikt kunnen bij de bereiding van voedsel of drinken, maar ook voor hun medicinale waarden. Een voorbeeld hiervan is echte heemst (*Althaea officinalis*). De bladeren en wortels van heemst zijn eetbaar, de bloempjes en andere plantendelen kunnen gebruikt worden om kruidendrank (aftreksels) van te maken.

De infectiegraad met darmparasieten van de bewoners van de Swifterbant nederzetting lijkt redelijk hoog geweest te zijn. Men kan zich afvragen of zelfmedicatie of ander gebruik van kruidenremedies werd toegepast. Hoewel maar één coproliet van Hardinxveld-Giessendam De Bruin is onderzocht, had deze een andere darmparasietencompositie dan die van Swifterbant. In Hardinxveld-Giessendam De Bruin zijn alleen darmparasieteneieren van mogelijk Fascioliidae (leverbot) aangetroffen. In Swifterbant zijn darmparasieteneieren van Diphyllobothriidae (vislintwormen), Opisthorchiidae (leverbot), en *Dioctophyma* (nierworm) gevonden. In vrijwel alle coprolieten van Swifterbant-S3 en S4 zijn darmparasieteneieren aanwezig die waarschijnlijk van een menselijke gastheer afkomstig zijn, namelijk zweepworm (*Trichuris trichiura*). Zweepworm is een goede indicator voor de aanwezigheid van mest in de bodem. In Swifterbant kan de frequente aanwezigheid van *Trichuris* een aanwijzing zijn dat de bodem werd vervuild met uitwerpselen, wat gezien kan worden als een langdurige aanwezigheid van mensen en dieren op een vaste locatie. De soortensamenstelling van darmparasieten van S3 en S4 is vrijwel hetzelfde. Hoewel de samenstelling niet helemaal hetzelfde is, is het goed mogelijk dat S3 en S4 tot hetzelfde nederzettingsterrein behoorden in de Swifterbant-periode. In ieder geval hadden ze dezelfde kook- en eetgewoonten.

Hoewel dit project als doel had het Swifterbantcultuur dieet te reconstrueren op basis van onderzoek aan menselijke coprolieten, is er uiteindelijk onderzoek gedaan aan coprolieten van zowel menselijke als dierlijke afkomst. Hierdoor kunnen we onze reconstructie alleen zien als die van een *community diet* (gemeenschappelijk eetpatroon). Het is gebleken dat het verhelderen van het eetpatroon gebaseerd op een individuele soort (mensen) erg uitdagend is, zo niet onmogelijk. Dit geldt zeker voor archeologische vindplaatsen zoals Hardinxveld-Giessendam De Bruin en Swifterbant-S3 en S4, waar mensen samen leefden met hun honden (en varkens) en ze vermoedelijk hetzelfde voedsel aten. Hoewel het er op lijkt dat de plekken waar geleefd werd schoon gehouden werden, waren de hygiënische omstandigheden op de nederzetting waarschijnlijk slecht, gezien het feit dat mens (en dier) besmet waren met meerdere darmparasieten.

1 Introduction

L. Kubiak-Martens & M. van der Linden

1.1 Why coprolites?

Coprolites are fossilised human or animal faeces rarely encountered in archaeological sites. The faecal remains fossilize either through desiccation or (partial) mineralisation.[1] They provide a unique opportunity for studying past human and animal diets. Coprolites typically contain a variety of macroscopic and microscopic plant and animal remains that form interrelated data sets for the reconstruction of diets.[2] In addition to the food remains, they also contain intestinal parasites and pathogens that affected the health of prehistoric populations. Coprolite studies are therefore also recognised as a way to assess the levels of infectious disease in prehistoric populations.[3] The recognition of the value of coprolite data has increased over the past decades, and Reinhard and Bryant designated coprolites as the 'missing links' for the understanding of human health and diet.[4]

Fossilisation of faeces is a rare event since faeces incline to degrade rapidly. In dry climates, dry caves, or dry rock shelter coprolites dehydrate and often survive.[5] In moist warm climates, the degradation process (by aerobic bacteria and fungi) will take a few days to weeks while in dry climates it may take several years.[6] Early stabilisation of the faeces is therefore necessary for coprolite formation. Also, the faecal composition and of the surrounding sediment affects the process of mineralisation. Carnivorous faeces contain dietary calcium phosphate in solution, due to presence of digested bone and in lesser amount flesh, which enables early mineralisation. The dung of herbivorous animals is rich in undigested vegetable fibre, although the dung of sheep and goats can have some mineral content.[7] Without early dehydration or mineralisation (entirely depending on external sources, e.g. ground water), dung would decompose and disaggregate.[8] Rapid burial under wet, anaerobic conditions, is widely assumed to be critical for the fossilisation of dung in most cases, since these coprolites are generally found in environments where rapid burial is possible (e.g. fluvial and lacustrine environments or refuse deposits).[9] Burial exposes faeces to groundwater and sets up suitable conditions for mineralisation. On some occasions, immediate burial might not be necessary if dung were deposited in water containing saturated or supersaturated concentrations of calcium carbonate or calcium phosphates.[10] Alternatively, when dung is deposited on wet soil, water evaporation and the wicking of mineral-laden ground water upwards into the faeces could provide another mechanism for relatively rapid mineralisation.[11] In summary, faeces will only fossilise under these specific conditions, either very dry or very wet and including the availability of minerals.

As faeces are produced over a short period within the body, they provide information on dietary patterns at a high temporal resolution and can be used to determine specific periods of seasonal use of a site.[12] Still, one should bear in mind that, in humans, food takes usually 1 to 3 days (unusually up to a week) to move through the digestive tract, depending on the amount and type of food that has been eaten, and on factors such as gender and metabolism.[13] Fry and Williams-Dean have each demonstrated that pollen persists in the intestines for days to weeks after the meal with which it was ingested, providing the opportunity for mixing of remains representing individual meals within the digestive tract.[14] Therefore, individual coprolites are not assumed to exclusively represent a single meal or a single day.[15]

Coprolite studies can also provide information about palaeoenvironmental conditions through the types of microfossils and macrofossils they contain.[16] Unfortunately, coprolites are still largely considered a niche topic, perhaps because they are not easily recognised on sites during archaeological excavations or later during the analysis phase, or cannot usually be attributed to a producer on the species level. Because of this, coprolites are rarely systematically collected in the field or regularly incorporated into archaeological studies, and only a few scientists devote their time to describing and interpreting this type of fossils.[17]

There are exceptions, however. Numerous coprolite studies were conducted as early as the 1960s and are continued today on prehistoric and native sites in North America, particularly in the arid southwest or Great Basin regions, where there is a prevalence of protected open sites and caves or rock shelters that provide favourable conditions for faecal preservation through desiccation.[18]

Fry was the first to propose a method of identifying the coprolites as human based on the

1 Hunt *et al.* 2012.
2 Reinhard & Bryant 1992.
3 Reinhard & Bryant 1992; Reinhard *et al.* 2019.
4 Reinhard & Bryant 1992.
5 Scott Cummings, personal communication
6 Hollocher & Hollocher 2012; Hunt *et al.* 2012.
7 Badal & Atienza 2007; Hunt *et al.* 2012.
8 Hunt *et al.* 2012.
9 Sawyer 1981; Hunt *et al.* 2012.
10 Hollocher & Hollocher 2012; Hunt *et al.* 2012.
11 Hunt *et al.* 2012.
12 Bryant 1974; Vermeeren 1998; Riley 2008; Reinhard & Bryant 1992.
13 National Institute of Health.
14 Fry 1970; Williams-Dean 1978.
15 Bakels 2006.
16 Reinhard & Bryant 1992.
17 Hunt *et al.* 2012; Green & Speller, 2017; Shillito *et al.* 2020a.
18 E.g. Moore, Fry & Englert 1969; Fry & Moore 1969; Heizer & Napton 1969; Reinhard & Clary 1986; Reinhard 1992; Reinhard & Bryant 2008; Reinhard *et al.* 2019.

color of the rehydrating liquid.[19] In other parts of the world, in New Zealand, for example, much work has been completed on Maori coprolites.[20] The earliest studies of human faeces in Europe focused on contexts such as latrines and cesspits rather than on the coprolites themselves.[21] This situation changed during the early 2000s when within geoarchaeology a greater focus was dedicated to human and animal faecal deposits in micromorphological soil and sediment thin sections.[22] Since then, this approach has been applied to many sites in different geographic regions and climatic zones to study early diet and health.[23]

It was also during this period that lipid biomarker analysis began to emerge in archaeology, including applications of faecal biomarkers.[24] Borry *et al*. developed coproID to aid in identifying the source organism of archaeological palaeofaeces and coprolites by applying a combined approach relying on both ancient host DNA content and gut microbiome

19 Fry 1970.
20 Horrocks *et al*. 2003.
21 Greig 1981.
22 Matthews 1995.
23 Shillito *et al*. 2011; Pichler *et al*. 2014; Huisman *et al*. 2014; Shillito *et al*. 2018.
24 Bull *et al*. 1998; Bull, Betancourt & Evershed 1999, Bull *et al*. 1999; Bull *et al*. 2000.

Table 1.1 General information on the Swifterbant sites investigated in this study

site	Age (cal BC)	Publication	RD Coordinates
Hardinxveld-Giessendam de Bruin	5500-4450	Louwe Kooijmans 2001	115.200/427.170
Swifterbant S3 & S4	4300-3400	Van Zeist and Palfenier-Vegter 1981; Raemaekers & de Roever 2020	168.267/510.251
Emmeloord-J78-91	2400-2100	Peeters 2007	180.221/525.355

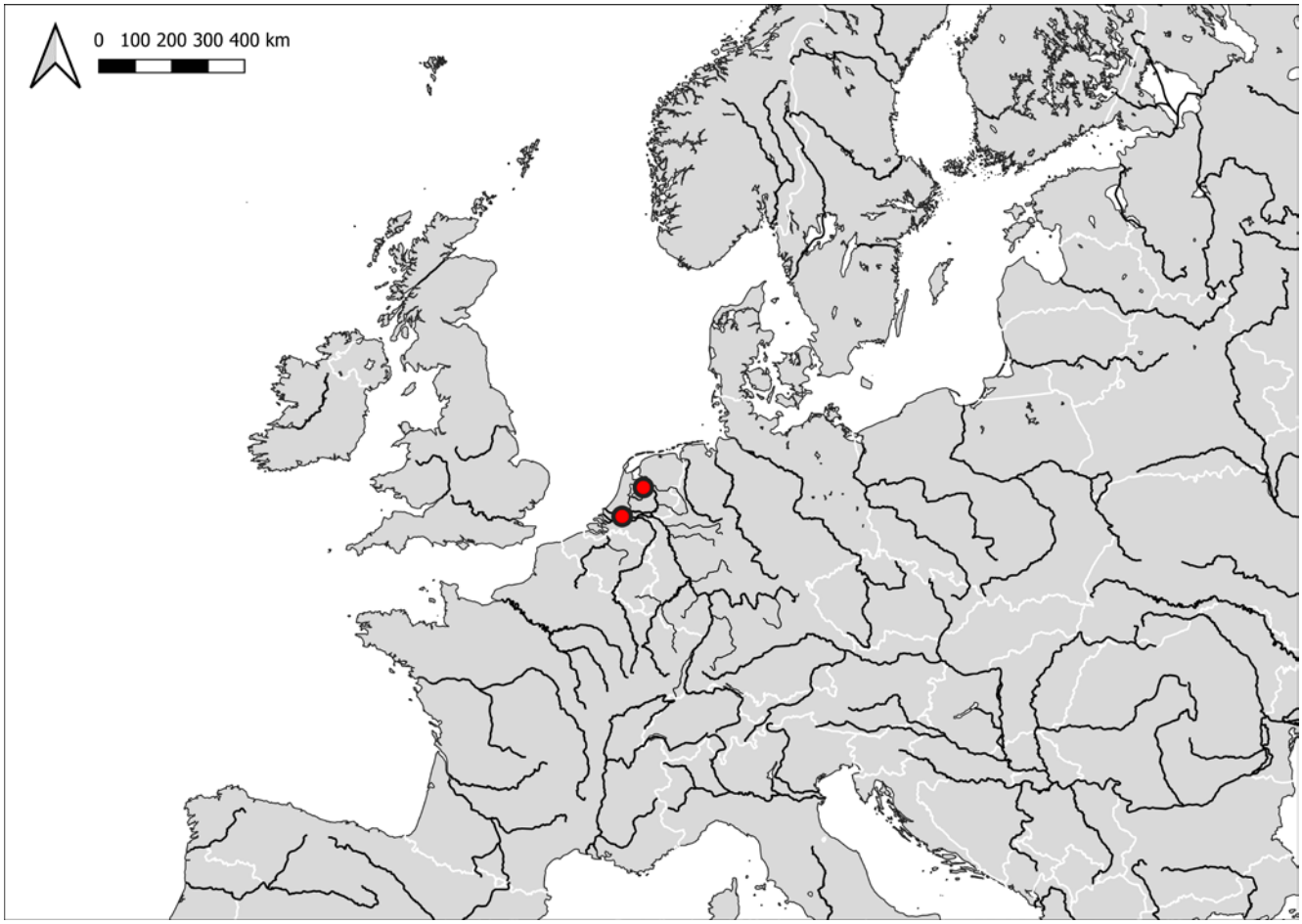

Figure 1.1 Map showing the location of the Netherlands within Northwestern Europe and the location of two research areas mentioned in this study: the Lower Rhine-Meuse delta in the western Netherlands and the Swifterbant area in the north-central part of the Netherlands (source: BIAX).

composition.[25] Most recently, Shillito *et al.* provided a critical review of the history and current state of research in human coprolite analysis in archaeology, encompassing macroscopic, microscopic, and biomolecular approaches.[26]

In the Netherlands, the finds of prehistoric human coprolites are rare and understudied. There are only a few archaeological sites (Hardinxveld-Giessendam De Bruin, Schipluiden, and Hekelingen) where coprolites were collected during excavations and eventually examined. A particularly large assemblage of coprolites (cattle, human/dog) was recovered at the Middle Neolithic Schipluiden.[27] At the Late Neolithic site Hekelingen some coprolites were found.[28] At all of the sites, however, only a morphological description and pollen analysis were performed. From the Swifterbant-S3 site, a series of coprolites were studied (shortly after the excavation campaigns) for the presence of intestinal parasites.[29]

1.2 Selection of key sites

The sites of interest for this study were defined as wetland sites and are located in two research areas (Table 1.1, fig. 1.1).

One is the Lower Rhine-Meuse delta, in the western part of the Netherlands, with river dune sites dated to the Late Mesolithic and the Early Swifterbant Culture. The transition from the Late Mesolithic to Early Swifterbant has been well documented in this area. One of the sites located in this area, Hardinxveld-Giessendam De Bruin (excavated in 1996, Fig. 1.2), dated to around 5500- 4450 cal BC, revealed the preservation of coprolites. These were dated to the end of Phase 1 of the site occupation (5500-5100 cal BC) and the beginning of Phase 2 (5100-4800 cal BC), and as such are associated with the Late Mesolithic use of the site.[30]

The other area is the Swifterbant area in the province of Flevoland (nowadays reclaimed land from the Zuiderzee-IJsselmeer since 1949) in the north-central part of the Netherlands. Here, the sites are located on the clayey levees in a former creek landscape and are all dated to the classic phase of the Swifterbant Culture, between 4300–4000 cal BC. There were two sites of primary interest to this study in this area:

Figure 1.2 A view of the excavation at Hardinxveld-Giessendam De Bruin in 1996 (source: L.P. Louwe Kooijmans).

Figure 1.3 A view of the excavation at Swifterbant-S3 in 1977 (source: RUG/GIA).

Swifterbant-S3 (excavated between 1972-1977, Fig. 1.3) and Swifterbant-S4 (excavated in 1974 and between 2005-2007). At both sites, many faecal remains were found in the refuse/ occupation layers. They were collected and preserved for future research. In addition, the coprolites from the Late Neolithic site J78/ Emmeloord in the Noordoostpolder, also in the province of Flevoland, were included in this study.

There are a number of additional key sites of the Swifterbant Culture in the Netherlands, including Hardinxveld-Giessendam Polderweg, Hazendonk, Brandwijk, Hoge Vaart-A27 and Schokland-P14. However, unfortunately, no coprolite remains were found at any of these

25 Borry *et al.* 2020.
26 Shillito *et al.* 2020a.
27 Van Waijjen & Vermeeren 2006.
28 Vermeeren & Kuiper 1993.
29 De Roever-Bonnet *et al.* 1979.
30 Bakels, Van Beurden & Vernimmen 2001.

sites. Two recently excavated (between 2016-2017) Swifterbant Culture sites, Tiel Medel-De Roeskamp and Nieuwegein, revealed the preservation of coprolite remains. The results of the study of these finds, however, will be presented in a separate publication.

1.3 Research approach

The project 'Neolithic Human Diet Based on Studies of Coprolites from the Swifterbant Culture Sites in the Netherlands' was one in a series of studies referred to as Pre-Malta research ('pre-Malta onderzoek'), and as such falls under the programme Knowledge for Archaeology. The programme aims to obtain datasets from (not yet fully elaborated) excavation data before the introduction of the Valetta convention in 2007. With the use of currently developed research methods and techniques, the Pre-Malta research programme enables the study of archaeological remains from old excavations, which means that substantial new knowledge can be obtained about the past.

The goal of the present study was to assess the diet and health of the Swifterbant Culture populations through the analysis of coprolites from sites excavated before 2007. The project was conducted in two distinct phases, Phase 1 and Phase 2.

1.3.1 Phase 1

Phase 1 consisted of two parts:

1. Initial examination – the coprolites were collected from archaeological depots in Lelystad and Alphen aan den Rijn (for details, see Chapter 4).
2. Chemical reconstitution phase (Chapter 5).

The 25 selected coprolites from four sites (Swifterbant-S3 and -S4, Hardinxveld-Giessendam De Bruin, Emmeloord-J78-91) were subsampled for gas chromatography-mass spectrometry (GC-MS) to define their faecal origin. Faecal lipid biomarkers (steroid compounds) were used as a group indicator, as the sterol profile varies according to whether an organism has a carnivorous, omnivorous, or herbivorous diet. A parallel analysis of bile acids was necessary for separating humans coprolites from those of other omnivores and herbivores.[31]

As all of the coprolites selected for this study were preserved by mineralisation, they were a less ideal choice for ancient human DNA (aDNA) preservation and analysis. This method, however, is often successfully applied to the desiccated coprolites.[32] Moreover, the possibility of contamination with mobile DNA from the sediment could not be eliminated. This can be problematic, particularly at sites where substantial amounts of water can move free DNA molecules between archaeological layers, which may result in contamination with modern DNA.[33] The Swifterbant Culture sites, as they were all located in wetland environments, would fall into this category of sites. Furthermore, the archaeological case studies in which the authenticity of DNA results was questionable also played a role in the choice of lipid biomarkers in this project. Lipid biomarkers are likely to be relatively stable.[34]

1.3.2 Phase 2

Phase 2 was devoted to the analysis of coprolite contents and also consisted of two parts:

In the first step of Phase 2, a total of 16 coprolites defined by the assessment of faecal lipid biomarkers as a) human, b) possibly human, c) animal (pig and ruminant) d) unknown producer, were scanned in a micro-CT scanner (for details about the selection, see Chapter 4.3). This method provided a direct and non-destructive way to achieve insights into the contents of the studied coprolites. Based on the micro-CT scans, bone material present in the coprolites was identified and, where possible, determined. For this project, micro-CT scanning was combined with the production of 3D digital models so that the plant and animal components embedded in coprolite matrices could be visualised and 3D-printed (Chapter 6).

In the second step of Phase 2, the scanning electron microscope (SEM) was applied to the same 16 coprolites to study their internal microstructure. The aim was to identify particles of plant tissues that had survived the process of food preparation and digestion and were now

[31] Elhmmali, Roberts & Evershed 1997; Bull, Evershed & Betancourt 2002; Shillito *et al.* 2018.
[32] Reinhard *et al.* 2019.
[33] See discussion in Poinar *et al.* 2009.
[34] Shillito *et al.* 2018.

embedded in coprolite matrices (Chapter 8). The bone remains that were separated or detached from the coprolite matrices during subsampling for microfossil analyses were identified (Chapter 7). Parallel with the SEM analysis, 13 coprolites were subsampled for microfossil analyses, including phytoliths (Chapter 9), pollen (Chapter 10), intestinal parasites (Chapter 11), and starch analyses (Chapter 12).

1.4 Research questions

The main research questions regarded the dietary diversity in the Swifterbant tradition, with emphasis on both plant and animal components. The evidence for the consumption of plant foods in general, and cereals in particular, was of great interest to this study. Furthermore, much attention was also dedicated to the presence of intestinal parasite remains in the attempt to infer the health conditions of the Swifterbant populations. To explore these themes, more specific and detailed research questions were formulated:

1. Who are the producers of the coprolites?
2. What were the Swifterbant peoples' regular meals?
3. How abundant are cereal remains representing cereals in the diet?
4. Can the crucial dietary shift, the introduction of cereals to the Swifterbant diet (from around 4300 cal BC), be identified and evaluated more accurately?
5. In what natural environment did the Swifterbant people live in? What can be said about seasonality?
6. What were the health conditions of the Swifterbant populations?

Also, three research questions from NOaA 2.0 were addressed:

- Question 7: How did the way of life change from the Late Mesolithic to the Late Neolithic?
- Question 8: Which landscape zones were used in the Late Mesolithic and Early Neolithic for habitation, hunting, arable farming and livestock?
- Question 22: What role did the exploitation of natural food resources play after the introduction of agriculture?

1.5 Project research team

A group of specialists using their own research methods generated a multidisciplinary data set which was combined and synthesised to best answer the research questions. All of the specialists have extensive research experience in the field of past human subsistence and diet. The team consisted of seven senior researchers working in various institutional settings (commercial and universities).

In the early stage of the project, Helen Mackay (Durham University) contributed GC-MS analyses to the project. The examination of sterols and bile acids biomarkers (together given the term 'faecal steroids') enabled the identification of human and non-human coprolites.

Dominique Ngan-Tillard (Delft University of Technology) used the micro-CT scanner to reveal the internal structures of the coprolites and to micromorphologically identify the presence of bone fragments and plant tissues embedded in coprolite matrices. She also produced 3D digital models so that the plant and animal remains could be visualised and 3D-printed.

Lucy Kubiak-Martens (BIAX Consult) used the scanning electron microscope (SEM) to study the internal microstructure of the coprolites and, in particular, the particles of plant tissues that survived the process of digestion and were now embedded in the coprolite matrices.

The study of fragmented animal bones embedded in coprolite matrices was carried out by Jørn Zeiler (ArchaeoBone).

Lisa-Marie Shillito (Newcastle University) contributed the phytolith analysis to the project and Karen Hardy (Universitat Autònoma de Barcelona) performed the starch analysis for evidence of diet and of plant foods that were consumed.

Marjolein van der Linden (BIAX Consult) examined pollen, intestinal parasites and other microfossils for evidence of diet, nutrition and health. The pollen analysis also contributed information on the environment and vegetation around the studied sites.

The project was coordinated by Lucy Kubiak-Martens, with organisational support from Rik Feiken (RCE) and scientific support from Hans Huisman (RCE and Groningen University).

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2 Swifterbant Culture

L. Kubiak-Martens

2.1 Introduction

The Swifterbant Culture was an indigenous Neolithic culture from which archaeological sites are found between the Scheldt valley in Belgium and the Weser valley in lower Saxony in Germany. Its territory may have reached as far as the Elbe river near Hamburg. In the Netherlands, the Swifterbant sites are concentrated in two main areas: one is in the western part of the country, in the Lower Rhine-Meuse delta, and the other in the north-central part of the country, in the province of Flevoland (Figs 2.1 and 2.2).[35]

The Swifterbant sites are often located on elevated grounds in the wetlands - on river dunes or natural small levees in the creek landscape. The majority of the sites seem to have been periodically used (however, repeatedly inhabited) for decades to a few centuries. For example, the river dune sites in the Lower Rhine-Meuse delta, Hardinxveld-Giessendam Polderweg and Hardinxveld-Giessendam De Bruin, are dated to around 5050-4950 cal BC and 5500–4450 cal BC, respectively. Hoge Vaart-A27, located on the coversand ridge along the former course of the Eem River in the southern part of Flevoland, is dated to around 4900-4300 cal BC. The levee and the dune sites in the Swifterbant area in Flevoland, including the Swifterbant-type sites-S3 and -S4 (dated to around 4300-4000 cal BC), were occupied for a few centuries at the most. All of these sites in both the Rhine-Meuse delta and Flevoland are considered to have been seasonally occupied (and the function not changing over time), but occasional year-round occupation cannot be excluded. The exception would be the Bergschenhoek site in the Lower Rhine-Meuse delta, located on a flat shore in the southern part of the delta, which is thought to have been inhabited for very brief periods, just a few days or a week at a time at the most.[36]

A prevailing theory is that the people of the Swifterbant Culture emerged as hunter-gatherers and then went through a long transition process of becoming farmers. The Mesolithic roots of the Swifterbant Culture are attested to the reliance on hunting, gathering, and fishing, and also in their lithic industry and in their manner of burying the dead, namely fully extended on the back. The neolithisation of the Swifterbant Culture is proposed as a process that evolved from contacts with the descendants of the Linear Band Pottery Culture (*Linearbandkeramik* or LBK) in adjacent southern and eastern areas. The process started in the Lower Rhine-Meuse area (well documented for Hardinxveld-Giessendam Polderweg) around 5000 cal BC with the production of pottery, either invented or adopted, marking the start of the Swifterbant Culture.[37]

At around 4600–4400 cal BC, there is some evidence that domesticated animals were incorporated into the Swifterbant economy. This evidence consists of small numbers of bones from domestic cattle, pigs, and sheep/goats from Hardinxveld-Giessendam De Bruin, and pig and cattle bones from Brandwijk.[38] It is difficult to assess the role of domestic animals in the subsistence economy during this early period (5th millennium BC) as, for example, the interbreeding between wild boar and domestic pigs at that time would have been very common.[39] The presence of domesticated cattle herds is suggested at both sites Hardinxveld-Giessendam De Bruin Phase 3 (around 4700–4450 cal BC) and Brandwijk, and more probably in Hazendonk (around 4020–3960 cal BC).[40] Domestic cattle bones are well represented in Swifterbant – S3.[41] The most secure indication for the presence of domesticated animals in the archaeological record of the Lower Rhine-Meuse area in the Early Swifterbant period are the few remains of sheep or goat bones at Hardinxveld-Giessendam De Bruin and pig bones from Brandwijk. The earliest dated domesticated animal specimen in the region comes from Hardinxveld-Giessendam De Bruin and is dated to 4520–4356 cal BC.[42]

The introduction of small-scale cereal cultivation into the Swifterbant subsistence followed around 4300–4000 cal BC and gradually gained more importance, but never seemed to become dominant before c. 4000 cal BC.[43]

35 Louwe Kooijmans 1993; Raemaekers 1999.
36 Louwe Kooijmans 1993, 2001a, 2001b; Raemaekers 1999.
37 Zeiler 1997; Raemaekers 1999, 2003, 2011; Louwe Kooijmans 2003.
38 after Raemaekers 2019; Çakırlar *et al.* 2020.
39 Çakırlar *et al.* 2020; Demirci *et al.* 2021.
40 Çakırlar *et al.* 2020; Demirci *et al.* 2021.
41 Zeiler 1997.
42 Çakırlar *et al.* 2020.
43 Louwe Kooijmans 2003; Raemaekers 1999, 2019.

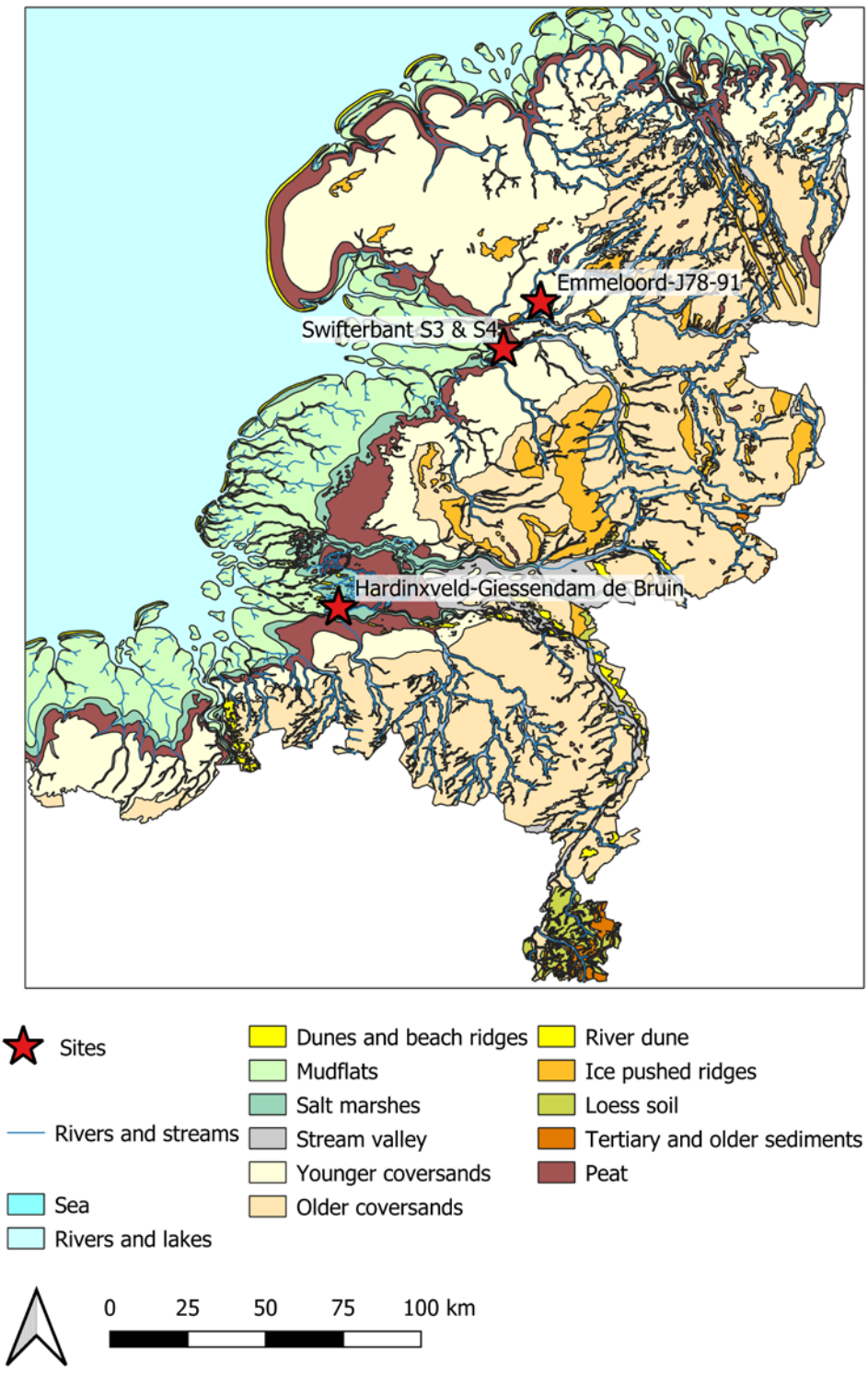


Figure 2.1 The Swifterbant settlement sites used in this study projected on the paleogeographic map of 5500 cal BC (source: Vos *et al.* 2020).

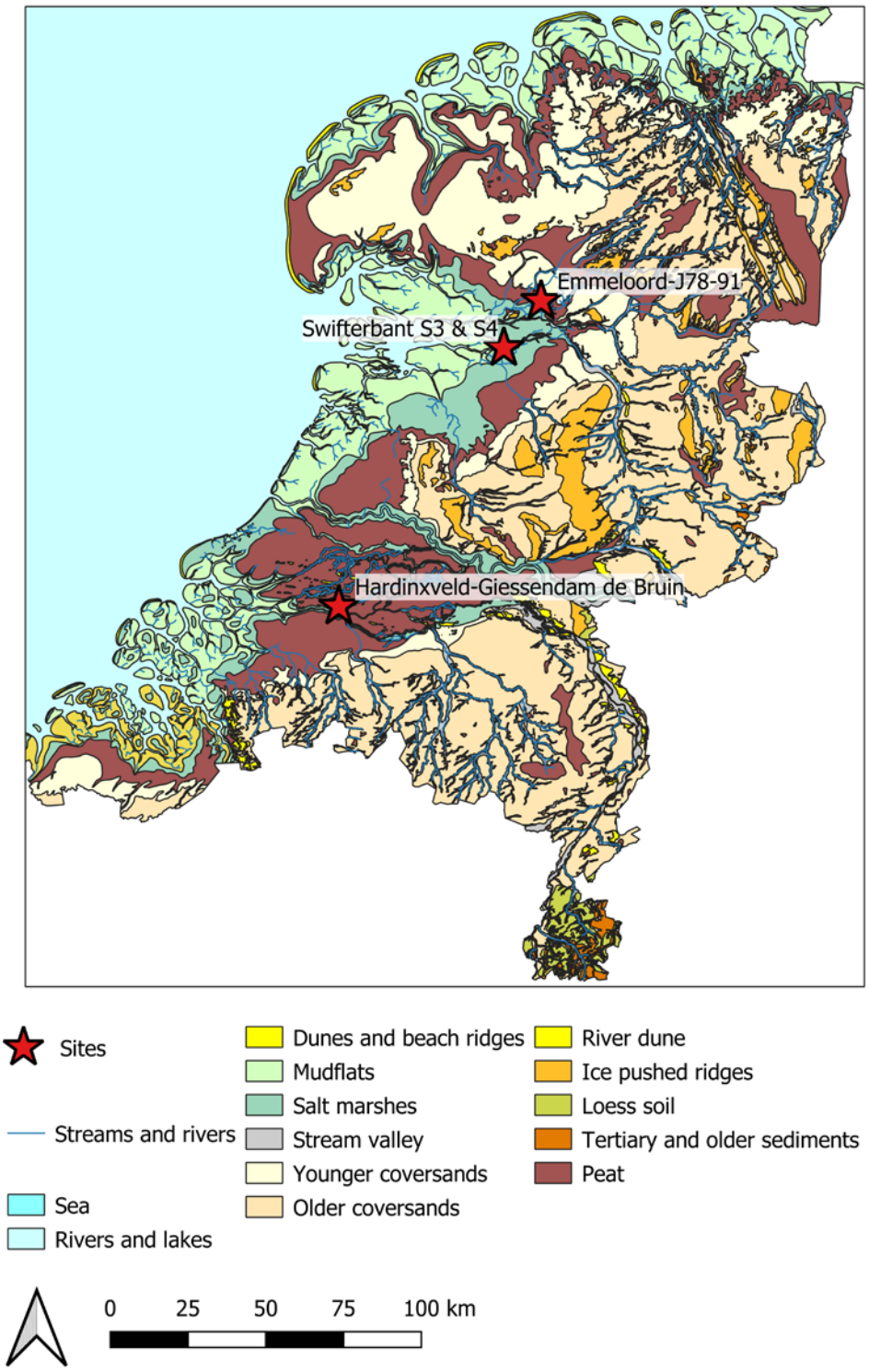


Figure 2.2 The Swifterbant settlement sites used in this study projected on the paleogeographic map of 3850 cal BC (source: Vos *et al.* 2020).

2.2 Cereals in the Swifterbant subsistence

The interpretation of the cereals from the Swifterbant sites has received much consideration over the years. The question of whether cereals were brought to the sites from elsewhere or were grown locally at the wetland sites has received much attention in this debate. Van Zeist and Palfenier-Vegter indicated the presence of threshing remains of naked barley as evidence for an early stage of crop processing at the S3 site in the Swifterbant area. This would favour the argument that naked barley (*Hordeum vulgare* var. *nudum*) and, possibly, also emmer wheat (*Triticum dicoccum*) were grown in the near vicinity of the site, possibly on the highest parts of the levees bordering the major creeks and on the river dunes at some distance from the site.[44] Van Zeist and Palfenier-Vegter's suggestion that the cereals would have been grown on higher parts of the levees is well supported by diatom analysis at yet another levee site in the Swifterbant area, the S2 site.[45] Significantly, the diatom analysis indicated periodic flooding (presumably in winter) which would have resulted in the sedimentation of a new nutrient-rich surface. This enriched surface would have stabilised in spring and would then have been available for cereal cultivation. In 2008, Cappers and Raemaekers presented a series of arguments in favour of small-scale cereal cultivation at the Swifterbant sites.[46] Based on archaeobotanical evidence, diatom analysis, archaeological artefacts (querns), and use-wear analysis, they concluded that cereal cultivation in the Swifterbant area could be convincingly confirmed. [47] Furthermore, they proposed that emmer and naked barley were cultivated as spring crops on small fields located on the natural levees of the Swifterbant area. They also concluded that cereals were not a central but a supplementary feature of the Early Neolithic Swifterbant subsistence economy.

The presence of small-scale cultivation has recently been further demonstrated by the find of what may have been small fields at the Swifterbant S4 site.[48] It was concluded that a combination of the field weed associations evidence, the cereal fragments recovered, and the cultivated field itself proved that cereals were grown on the river banks in the direct vicinity of the Swifterbant settlements.[49] The evidence of cultivated fields on this levee site in the form of tilled layers, and also on two other sites in the area (S2 and S3) indicated that tillage formed a regular part of the Swifterbant subsistence strategies during the Early Neolithic and strengthened the interpretation of local cultivation. The period of around 4300-4000 cal BC is considered to be the introduction of cereal cultivation in the Swifterbant Culture.[50] There is no archaeobotanical evidence at the Swifterbant sites for the cultivation or use of pulses or oil plants.

The Swifterbant sites from the classic phase of this culture (around 4300-4000 cal BC), yielded the remains of two cereal species, naked barley and emmer wheat. One charred grain of possibly bread wheat (*Triticum* cf. *aestivum*) from Swifterbant S3 was concluded by Van Zeist and Palfenier-Vegter to have likely derived from a deformed emmer wheat kernel.[51]

Naked barley and emmer wheat were long considered a standard package of the Swifterbant Culture.[52] At the most recently excavated Swifterbant site, Tiel Medel-De Roeskamp (dated to around 4300-4000 cal BC) in the Dutch Rhine-Meuse river area, the spectrum of cereals yielded the remains of einkorn (*Triticum monococcum*) and the tetraploid variety of free-threshing wheat (*Triticum durum/turgidum*) in addition to naked barley and emmer wheat. The Swifterbant farmers from Medel would have adopted the tetraploid naked wheat (and also emmer, einkorn and naked barley) either from the southeast, by direct contact with the Bischheim zone, or from the south through contact with the early Flemish Michelsberg farmers.[53] The Neolithic elements (ceramic, stone artefact imports, and house plans) all point to contact with the Rössen/Bischheim/Michelsberg tradition of the German Rhineland.[54]

Through all the neolithisation phases, however, hunting, fishing and gathering wild plants for food played a significant role in Swifterbant subsistence strategies. Within the wetland environment, a subsistence model developed, described by Louwe Kooijmans as an 'extended broad spectrum economy' in which the gathering of wild plant foods, fishing, and hunting would have been combined with animal farming and cereal cultivation.[55] A major economic transition is seen only later with the

44 Van Zeist & Palfenier-Vegter 1981.
45 De Wolf & Cleveringa 2005.
46 Cappers & Raemaekers 2008.
47 Cappers & Raemaekers 2008.
48 Huisman & Raemaekers 2008; Huisman, Jongmans & Raemaekers 2009; Schepers 2014.
49 Schepers 2014.
50 Huisman & Raemaekers 2014.
51 Van Zeist & Palfenier-Vegter 1981.
52 Van Zeist & Palfenier-Vegter 1981; Cappers & Raemaekers 2008; Schepers & Bottema-Mac Gillavry 2020.
53 Kubiak-Martens (in prep.).
54 Ten Anscher & Knippenberg (2022).
55 Louwe Kooijmans 1993, 2003.

introduction of *Trichterbecherkultur* (TRB) pottery in c. 4000 cal BC.[56] Also, around 4000 cal BC or somewhat later, cattle bones increasingly outnumber pig/wild boar bones, pointing to a structural shift in the subsistence economy.[57] The perception of domestic cattle may have changed profoundly, judging from the ritual depositions of cattle horns. The outcome of this process was a society in which both agriculture and animal husbandry (especially domestic cattle) took centre stage.[58]

2.3 Wild plant and animal food resources

The peoples of the Late Mesolithic - Early Swifterbant sites in the Lower Rhine-Meuse area used a wide range of wild plant and animal foods. A variety of nuts, fruits, and berries were collected and processed for food, as indicated by their charred remains from Hardinxveld-Giessendam Polderweg and Hardinxveld-Giessendam De Bruin, including hazelnut (*Corylus avellana*), water chestnut (*Trapa natans*), acorn (*Quercus*), wild apple (*Malus sylvestris*), hawthorn (*Crataegus monogyna*), dogwood (*Cornus sanguinea*), and possibly guelder rose (*Viburnum opulus*).[59] Numerous charred seeds of yellow water-lily (*Nuphar lutea*) and white water-lily (*Nymhaea alba*) found in surface hearths in Hoge Vaart-A27 suggest that seeds of both species might have been processed for food.[60] Starchy root tubers of lesser celandine (*Ranunculus ficaria*, syn. *Ficaria verna*) were also likely used as food, as suggested by the charred remains from Hardinxveld-Giessendam Polderweg and Hoge Vaart-A27.[61]

A broad spectrum of animal resources was also exploited during the Late Mesolithic - Early Swifterbant period, including large and small game, fowl and fish. The bones of deer (Cervidae), wild boar/domestic pigs (*Sus* sp.), otter (*Lutra lutra*), and beaver (*Castor fiber*) were the most abundantly recovered mammal remains. Otter and beaver were hunted in large numbers and their meat and fur were used.[62] The high frequency of fish bone remains recovered from the Late Mesolithic - Early Swifterbant sites in the Lower Rhine-Meuse area suggests that fishing was an important, if not key, activity at all of the early sites. The fish remains provide evidence for freshwater fish, including pike (*Esox lucius*), perch (*Perca fluviatilis*), catfish (*Silurus glanis*), and the carp family (Cyprinidae), as well as anadromous fish, including sturgeon (*Acipenser sturio*), eel (*Anguilla anguilla*), salmon/sea trout (*Salmo salar* cf. *trutta*), allis shad (*Alosa alosa* L.) and, occasionally, marine species (mullet family, Mugilidae). Bird bones are less common and mainly comprise duck (Anatidae), especially mallard (*Anas platyrhynchos*), suggesting that the hunting of wildfowl might have been a less important subsistence activity.[63]

During the classic phase of the Swifterbant Culture, in addition to the use of cereals, a variety of nuts, fruits and berries were also collected, including hazelnuts, water chestnuts, acorns (possibly), wild apples, hawthorn berries, dogwood berry-like drupes, rose (*Rosa*) hips, and blackberry (*Rubus fruticosus*).[64] Root vegetables such as tubers of sea club-rush (*Bolboschoenus maritimus*) would also have been used.[65]

In addition to plant foods, a broad spectrum of animal resources was also used, including domestic animals, such as pig, cattle, and sheep/goat, as well as game animals, such as beaver, otter, wild boar, and red deer. The game animals were hunted for both their fur and meat.[66] Cattle husbandry seems to be more important at S4 and S3 than at other sites in the Swifterbant area.[67] In addition to mammals, fish bone remains from the sites in the Swifterbant area provide clear evidence for both anadromous (sturgeon, grey mullet and eel) and freshwater (pike, perch and catfish) species.[68] Although it is difficult to determine the relative importance of the animal species found, the small number of bird bones may indicate the limited importance of fowling.[69]

56 Ten Anscher 2012; Raemaekers 2012.
57 Gehasse 1995.
58 Raemaekers 2003; Raemaekers 2019.
59 Bakels & Van Beurden 2001; Bakels, Van Beurden & Vernimmen 2001.
60 Brinkkemper *et al.* 1999.
61 Bakels & Van Beurden 2001; Brinkkemper *et al.* 1999.
62 Zeiler 1997.
63 Brinkhuizen 1979; Zeiler 1997.
64 Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020; Kubiak-Martens (in prep.).
65 Schepers & Bottema-Mac Gillavry 2020.
66 Zeiler 1997.
67 Kranenburg & Prummel 2020.
68 Brinkhuizen 1976; Clason 1978.
69 Kranenburg & Prummel 2020.

3 The archaeological sites and their landscape

L. Kubiak-Martens & M. van der Linden

3.1 Introduction

The coprolite samples incorporated in this study are from four archaeological sites located in two major research areas, including Hardinxveld-Giessendam De Bruin in the Lower Rhine-Meuse river delta, and the Swifterbant-S3 and -S4 sites and Emmeloord-J78-91 in Flevoland. As the material from Emmeloord-J78-91 was eliminated in the early phase of the project, no further information about this site is provided.

3.2 Hardinxveld-Giessendam De Bruin

Hardinxveld-Giessendam De Bruin is one of many river dune sites located in the Lower Rhine-Meuse river delta in the western Netherlands (Figs 3.1 and 3.2). This site and the neighbouring Hardinxveld-Giessendam Polderweg were inhabited during the Late Mesolithic (5th millennium BC), but the use of De Bruin, in contrast to Polderweg, continued into the Early Neolithic (Early Swifterbant) (Fig. 3.3). Three phases of occupation were distinguished at the De Bruin site. Phase 1, the oldest settlement, dated to c. 5500 to 5300 cal BC, Phase 2, witnessing the introduction of pottery, dated to c. 5100 to 4800 cal BC, and Phase 3, when the first domestic animals appeared at the site, dated to c. 4700 to 4450 cal BC.[70]

The river dunes, which were formed in the large riverbeds at the end of the Late Pleistocene and rose above the surrounding water in a riverine landscape, provided dry spots for occupation.[71] The river dunes of De Bruin and Polderweg were situated in an area with slowly flowing rivers with low banks and extensive marsh vegetation dominated by reed and sedges. Alder carr around the dunes are indicated by the pollen and macrofossil records.[72] During Phase 1, other species would also have been found in the marshes, including bulrush (*Typha latifolia*), common club-rush (*Schoenoplectus lacustris*), branched bur-reed (*Sparganium erectum*), great water dock (*Rumex hydrolapathum*), water-plantain (*Alisma plantago-aquatica*), fine leaf water dropwort (*Oenanthe aquatica*), northern water hemlock (*Cicuta virosa*) and bittersweet (*Solanum dulcamara*). The marsh vegetation would have diversified further during Phase 2. Many additional species would have

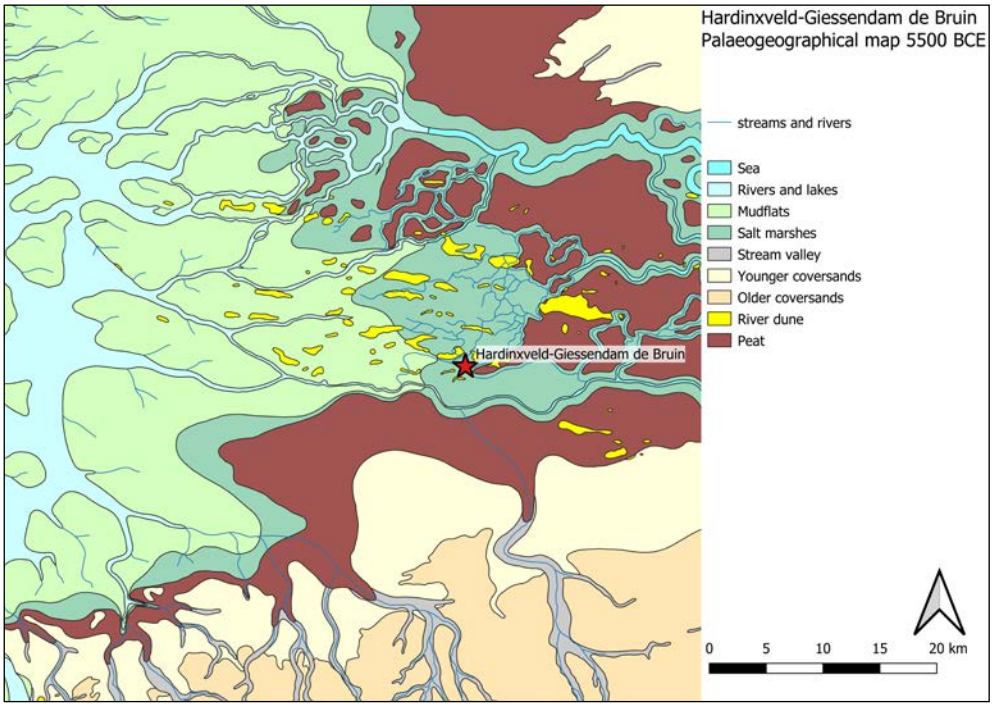


Figure 3.1 Hardinxveld-Giessendam De Bruin projected on the paleogeographic map of 5500 cal BC (source: Vos *et al.* 2020).

70 Louwe Kooijmans 2001b.
71 Louwe Kooijmans 1993, 2003.
72 Bakels, Van Beurden & Vernimmen 2001.

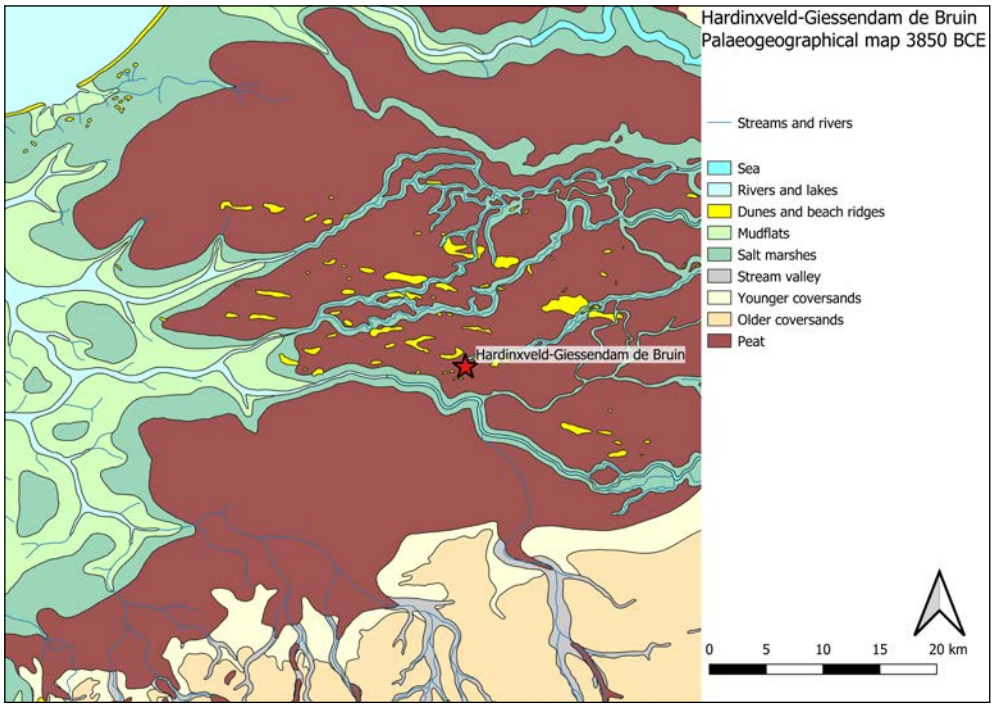


Figure 3.2 Hardinxveld-Giessendam De Bruin projected on the paleogeographic map of 3850 cal BC (source: Vos *et al.* 2020).

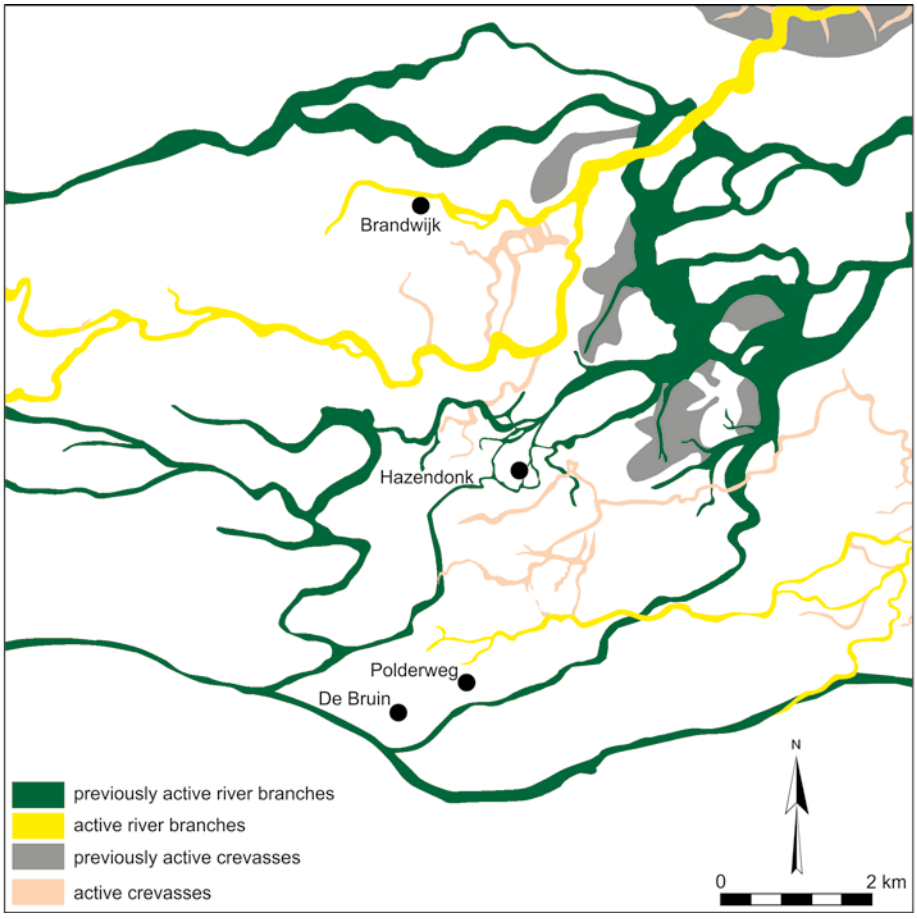


Figure 3.3 Hardinxveld-Giessendam De Bruin and other archaeological sites in the Lower Rhine-Meuse river delta in relation to various river branches. The white area consisted of marshes and lakes (Vos & de Vries 2013; adapted from Demirci *et al.* 2021).

grown in the marshes and riparian vegetation around the De Bruin dunes, including lesser water-parsnip (*Berula erecta*), marsh marigold (*Caltha palustris*), meadowsweet (*Filipendula ulmaria*), gypsywort (*Lycopus europaeus*), spiked loosestrife (*Lythrum salicaria*), milk-parsley (*Peucedanum palustre*), reed canary grass (*Phalaris arundinacea*), water pepper (*Persicaria hydropiper*) and valerian (*Valeriana officinalis*). Open water is also well represented in the macroremains records, as demonstrated by the presence of white water-lily (*Nymphaea alba*), frogbit (*Hydrocharis morsus-ranae*), water nut (*Trapa natans*) (all in Phase 1) and eight-stamened waterwort (*Elatine hydropiper*) and yellow pond-lily (*Nuphar lutea*) (in Phase 2), with the latter species indicating the rising of the water table. During the final occupation phase, the diversity and frequency of the occurrences of marsh and water plants are high due to the continually rising water table.

During all of the occupation phases, the wet area around the dunes would have been only accessible by boat. Trees of lime (*Tilia platyphyllos*) and oak would have grown on the dunes. These would have been accompanied by smaller trees and shrubs of hazel, hawthorn, apple and mountain-ash (*Sorbus aucuparia*). The dry dune surface, however, was becoming smaller due to rising water levels and during Phase 3 was limited to the northwestern corner of the dune. By 3850 cal BC the area was covered by peat-forming vegetation (see Fig. 3.2).

3.3 Swifterbant area, S3 and S4 sites

The S3 and S4 sites are neighbouring sites located on the clayey levees of a small creek (or the creek bank of a small river system) in eastern Flevoland, near Swifterbant. Both are dated to the classic phase of the Swifterbant Culture and were occupied at some time in the period 4300–4000 cal BC. The recently conducted studies on the comparison of archaeological and archaeobotanical remains from both sites suggest that S3 and S4 may actually have functioned as a single Swifterbant settlement.[73] Together with many other levee sites in the area, they belong to the prehistoric landscape of large and small creeks bordered by natural levees and adjacent sand ridges, as well as nearby dunes (Figs 3.4, 3.5 and 3.6).[74]

There has been much debate concerning the degree of tidal movement and brackish

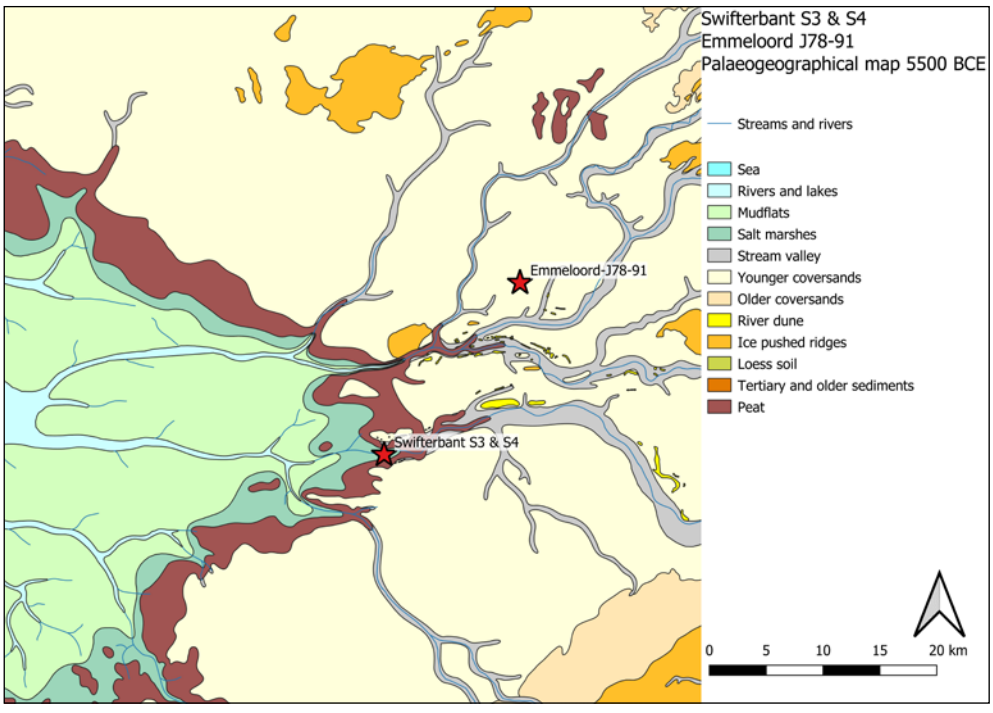


Figure 3.4 Swifterbant S3 and S4 and Emmeloord-J78-91 projected on the paleogeographic map of 5500 cal BC (source: Vos *et al.* 2020).

[73] Raemaekers & De Roever 2020; Schepers & Bottema-Mac Gillavry 2020.
[74] Ente 1976; Devriendt 2014.

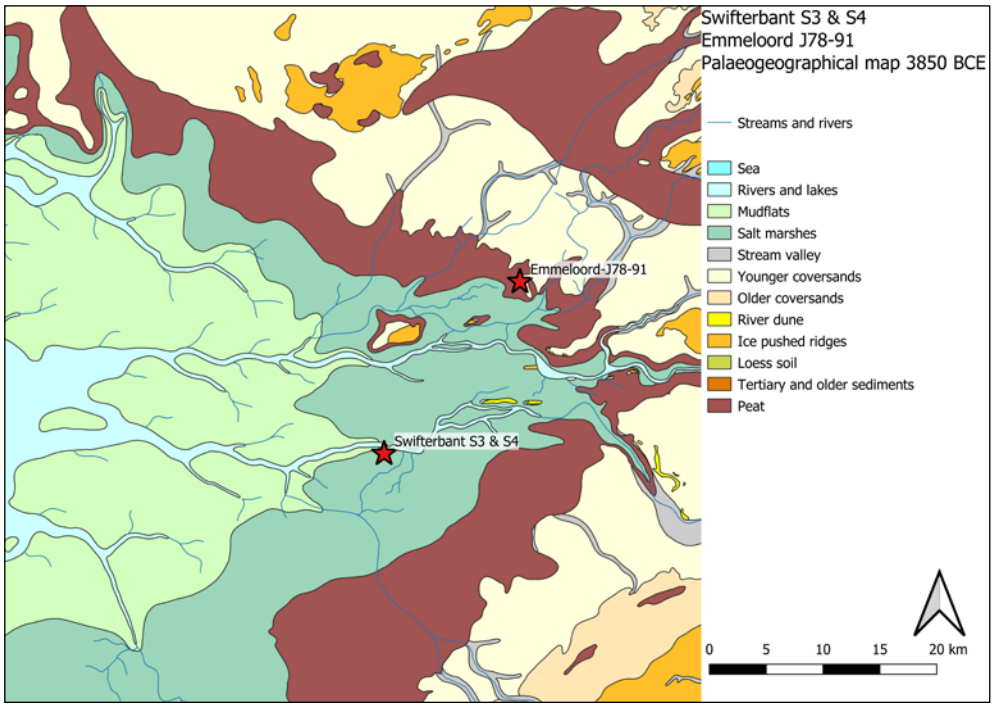


Figure 3.5 Swifterbant S3 and S4 and Emmeloord-J78-1 projected on the paleogeographic map of 3850 cal BC (source: Vos *et al.* 2020).

conditions in the area during the Swifterbant occupation. Although cut off from the sea, the area was, for large parts of the Holocene, a coastal lagoon. At the time of the Swifterbant occupation of the area, however, it was a (predominantly) freshwater tidal estuary that was connected through the creek system to the North Sea.[75] Minor brackish conditions occurred only occasionally when the levees were flooded, presumably during winter storms when saltwater would have penetrated the area through the creek system. During the rest of the year, it was a freshwater wetland. Within this wetland, drier patches on the higher dunes located above the maximum water level and elevated banks along the branches of the small river system were available for habitation.[76]

The sporadic presence of plant species characteristic of halophytic vegetation, such as sea aster (*Aster tripolium*), salt marsh rush (*Juncus gerardii*) and glasswort (*Salicornia europaea*) in the macroremains assemblages from the S3 site may suggest that these entered the area during the storm surges and did not constitute part of the local vegetation.[77] Open water would have been abundantly present in the creek system, both in the stream channels and in the low-lying back-swamps behind the levees. The water in both the stream channels and the ponds was likely fresh, even though some of the aquatic plants present in macroremains from S3, such as curled pondweed (*Potamogeton crispus*), soft hornwort (*Ceratophyllum submersum*) and horned pondweed (*Zannichellia palustris*), are tolerant of slightly saline water and would have grown in both fresh and brackish water. There must also have been bodies of freshwater - possibly in the lowermost parts of the back swamps - where plants typical of freshwater habitats such as white water-lily would have thrived.[78] The water meadows would have developed on the floodplain and would have become a grazing zone dominated by grasses.[79] Willow shrubs and marsh vegetation (particularly reed and various club-rush species) would have grown on - or perhaps even dominated - the banks and/or along the stream channels, whereas alder carr vegetation, which was quite common in the area, would have been found in the back-swamps and the more permanently wet areas of the floodplain. Alder must have been the most common tree in the vicinity of the settlements. The highest parts of the levees would have been covered by deciduous forest communities attributable to the order of the *Alno-Padion*, which includes forest vegetation that requires

75 Ente 1976; De Roever 2004; Schepers & Woltinge 2020.
76 De Roever 2004; Schepers 2014; Schepers & Bottema-Mac Gillavry 2020.
77 Van Zeist & Palfenier-Vegter 1981.
78 Van Zeist & Palfenier-Vegter 1981.

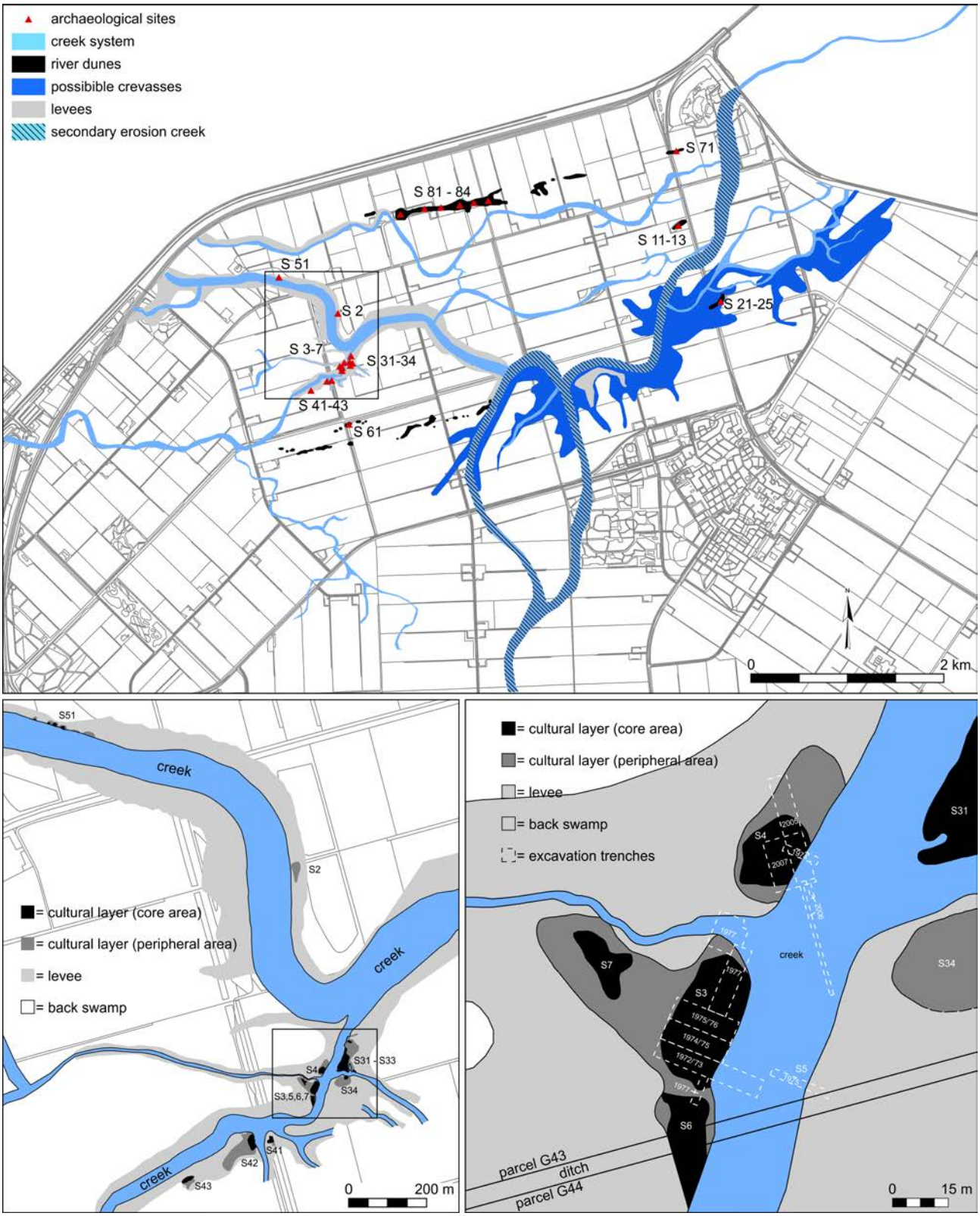


Figure 3.6 Map showing the location of the Swifterbant sites along with the freshwater creek system (a). The western part of the Swifterbant creek system with the location of the S3 and S4 sites (b & c), adapted from Raemaekers & De Roever 2020.

incidental flooding by the rivers. Even though the palaeobotanical data revealed the presence of oak, elm, ash, lime, crab apple and poplar, there is some doubt as to whether a well-developed forest would have been present in the vicinity of the Swifterbant settlement or was, instead, limited to the dunes at some distance.[80]

Human impact on the natural vegetation resulted in ruderal vegetation in which arable weed communities developed. A large number of species in the S3 and S4 assemblages are characteristic of ruderal/synanthropic vegetation, which would have been very common in the vicinity of the Swifterbant settlement.[81]

At both sites S3 and S4, occupation surfaces were renewed with the regular deposition of reed bundles. At S3, the accumulation of occupation deposits up to 75 cm thick, in which there were layers of reed stems, scattered wood chips, bark, and twigs, were frequently observed during the fieldwork.[82] At S4, the occupation surface started with the deposition of reed materials, in which typical settlement debris was found. This layer was covered with a natural clay layer and was subsequently used as a cultivated field. Next, the site was reused as a settlement and a c. 50 cm think reed layer was deposited. Later, this layer - the major anthropogenic layer - became covered with clay deposits.[83] At S3, where the site stratigraphy is very similar to S4, a well-preserved cultivated field was documented in the same stratigraphic position.[84]

A remarkable find was revealed at the Swifterbant S4 site. A bead made of a single carbonised stone of sloe (*Prunus spinosa*) was found there.[85] Two things are peculiar about this find. Firstly, sloe has not been identified earlier in the Swifterbant archaeobotanical record, neither in the Swifterbant area nor at other extensively studied sites (for example, Hoge Vaart or Tiel Medel). It seems that the use of sloe plums is more of a Middle Neolithic tradition in the coastal area and is associated with the Hazendonk sites such as Schipluiden.[86] Secondly, the tradition of bead-making from seeds and fruit stones is not known from the prehistory of the Netherlands, but it seems to be a phenomenon in the Neolithic period of middle and eastern Europe.[87] One of the best analogies for the Swifterbant S4 sloe bead are the finds from the Neolithic lakeshore settlements, Hornstaad Hörnle (3917-3905 cal BC) and Arbon Bleiche 3 (3385-3370 cal BC), both located on the shores of the Bodensee/Lake Constance.[88] The specialised production of sloe stone beads has been ascribed to Hornstaad Hörnle. It was also suggested that the beads could have been sewn into textiles or worn as a chain or pendant.

79 Schepers & Bottema-Mac Gillavry 2020.
80 Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
81 Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
82 Van Zeist & Palfenier-Vegter 1981.
83 Schepers & Woltinge 2020.
84 Huisman & Raemaekers 2014.
85 Schepers & Bottema-Mac Gillavry 2020.
86 Kubiak-Martens 2016.
87 Schlichtherle 1988, after Schepers & Bottema-Mac Gillavry 2020.
88 Schepers & Bottema-Mac Gillavry 2020.

4 Selection of the coprolites

L. Kubiak-Martens

4.1 Introduction

Human faecal remains are often difficult to identify with certainty. In particular, distinguishing human from canine coprolites can be challenging because they are often similar in size and shape, and they tend to occur together at archaeological sites. Moreover, dogs often consume food similar to those of humans because of provisioning or refuse scavenging, or consuming human faecal remains, making their faeces difficult to distinguish from humans based on dietary contents. This difficulty is underscored by examining a coprolite record from Nubia (Sudan) where 48 coprolites were associated with naturally mummified human bodies. Individual (daily or multiple days of) meals there appear to have been extremely varied, even in a population of coprolites that, by their association, were certainly of human origin.[89]

Another complicating factor is the great variety of shapes and sizes of human faeces and the fact that many faecal remains lack distinctive morphological features or are often fragmented, which further complicates the determination of the source origin.[90] In the Netherlands, as in Europe in general, coprolites are usually preserved by mineralisation.[91] There are exceptions, however. For example, at the Neolithic pile-dwelling sites in southern Europe, the coprolites are usually preserved in waterlogged conditions.[92] Large assemblages of waterlogged coprolites of both human and animal origin from one of these lakeshore settlements, Arbon Bleiche 3 on Lake Constance in Switzerland were extensively studied.[93] Also, excellent preservation of human paleofeces was currently revealed from the Hallstatt salt mines in Austria dating from the Bronze Age to the 18th century AD. The constant low annual temperature and high salt concentrations inside the mine preserved both plant macro-remains and biomolecules (DNA and protein) in the paleofeces.[94]

In this chapter, the sampling strategy applied to coprolites from the sites concerned in this study is presented. Two stages, selection based on the morphology of the coprolites and further selection based on initial lipid extractions are described.

4.2 Identifying and sampling the coprolites

The initial recognition of coprolites occurs during excavation. The observations made by archaeologists at this stage are essential to meaningful analysis. Also at this level, the preliminary sorting into categories of human versus non-human coprolites can be tentatively made based on morphology and size.[95] It was interesting to see that this early attempt to separate animal dung from other coprolites was applied to many of the faecal remains recovered from the Swifterbant -S3 and -S4 sites (Figs 4.1 and 4.2). They were well recognised in the field and then described during the sorting stage as either *keutels* (Dutch for faecal remains in the form of rounded specimens/pellets) or *mest* (animal dung).

Reinhard and Bryant recommended a method for working with coprolite remains consisting of four distinct steps: (1) during excavation, (2) during the initial examination, (3) during the chemical reconstitution phase, and (4) during the analysis of the coprolite contents.[96] Studies of large series of coprolites indicate that usually 80-90 percent of the most common food components are found after

89 Cummings 1989.
90 Reinhard & Bryant 1992, 2008; Poinar *et al.* 2009.
91 Bakels, Van Beurden & Vernimmen 2001; Van Waijjen & Vermeeren 2006.
92 Tolar & Galik 2019; Akeret & Jacomet 1997; Kühn *et al.* 2013.
93 Jacomet & Brombacher 2005; Jacomet, Leuzinger & Schibler 2005.
94 Maixner *et al.* 2021.
95 *Reinhard & Bryant* 2008.
96 *Reinhard & Bryant* 1992.

Figure 4.1 The archaeological depot of the Province of Flevoland in Lelystad. Photo shows one of the carton boxes filled with coprolites from Swifterbant-S3 (excavated between the years 1972 and 1979) (photo: L. Kubiak-Martens).

Figure 4.2 During the sorting stage, small paper bags had been used to store the coprolites. a. They were described either as a *keutel* (a pellet) or *mest* (animal dung); b. Some were recommended as beautiful specimens for a museum collection (photo: L. Kubiak-Martens).

15 - 20 coprolites in a series have been examined. Thus, a minimum sample size of 20 coprolites appears to be sufficient to identify the major dietary items. Coprolites and coprolite fragments are sometimes collected in situ during archaeological excavations, but most often they are found during screening when soil is being separated from artefacts.[97] Reinhard and Bryant also suggested that to optimise data recovery from coprolites, animal remains, plant macroremains, pollen, phytolith, and parasite should be analyzed. These data sets can then be integrated into a comprehensive reconstruction of the diet. For most studies, it is important to examine a fairly large fragment (>5 g) of each coprolite to obtain a representative number of dietary components. It is usually sufficient to cut a coprolite in half along its longest axis and analyse one of the halves. When coprolite samples are fragmented or when one half of a coprolite is smaller than 5 g, a different strategy must be adopted by combining several fragments from the same specimen. In some cases, the whole specimen will need to be processed if the total size is quite small.[98]

In archaeological studies, the coprolites of human origin and the domesticated animals associated with them are usually of main interest. In our study, the primary focus was specifically on human coprolites. Nevertheless, as at any archaeological site including the sites concerned in this project, the coprolite assemblages comprise both human and animal faecal remains.

Despite the limitations of morphological analysis as a species indicator, a description and photography should always be made before any further analysis, given that the majority of analytical methods are destructive.[99] Morphological criteria can be used in the identification of taxonomic groups, which can be subjected to subsequent analysis.[100] A large assemblage of coprolites from the Neolithic site of Schipluiden in the Netherlands, for example, revealed diverse morphological types which were successfully grouped into three categories and thereafter attributed to cattle, possibly cattle, and dog/human.[101] Selected coprolites were later also subjected to pollen analysis.[102] The Schipluiden assemblage, as well as other archaeological coprolite assemblages, showed that dung from herbivores such as bovids and ovicaprids is usually distinct enough to be identified as non-human. Coprolites from other species, however, such as dogs and pigs, can be easily confused if based exclusively on gross morphology. Both species can have very variable omnivorous diets and produce coprolites that are morphologically similar to those of humans.[103]

Depending upon the diet and the interval between bowel movements, the type of food consumed, and the health and age of the individual, human faeces can appear as large segmented pellets, cylindrical sausage-like masses, or as amorphous pads resembling the dung of some large herbivores such as cattle.[104] This results in a potentially wide range of morphological types which can be expected in human faecal remains. This is perhaps best

97 *Reinhard & Bryant* 2008.
98 Reinhard & Bryant 1992.
99 Jouy-Avantin *et al.* 2003; Shillito *et al.* 2020a.
100 Chame 2003; Shillito *et al.* 2020a.
101 Van Waijjen & Vermeeren 2006.
102 Bakels 2006.
103 Van Waijjen & Vermeeren 2006; Shillito *et al.* 2020a.
104 Reinhard & Bryant 1992.

illustrated by the *Bristol Stool Form Scale* which is a diagnostic medical scale designed to classify the form of human faeces into seven categories (Fig. 4.3). One should bear in mind, however, that these morphological types might not have been the norm for prehistoric populations. Therefore, applying the *Bristol Stool Form Scale* as a reference for archaeological faecal remains should be done with some caution.

4.3 Sampling Swifterbant coprolites based on morphology

A total of 328 coprolites from Swifterbant-S3, 47 coprolites from Swifterbant-S4, and two coprolites from Emmeloord-J78-91 were recovered and stored in the province of Flevoland archaeological depot in Lelystad. From Hardinxveld-Giessendam De Bruin, five coprolites stored in the province of South Holland archaeological depot in Alphen aan den Rijn were available for study.

As the largest number of coprolites was recovered from the S3 site, this assemblage was used in the attempt to categorise the coprolites based on their morphological features. Of the 328 coprolites from the S3 site, the majority were of animal dung, likely from herbivorous producers (often flattened cake-like, fragmented and with ragged edges). Thirty coprolites from this series, mainly of non-herbivorous origin, were selected to be morphologically defined. Based on the morphological features (such as shape and the presence of cracks and segments) observed with the naked eye and with the use of the stereo light microscope, these coprolites were sorted into the following morphological categories: sausage-like shape (*n*=9), separated lumps with a segmented surface (possibly originally sausage-shaped but lumpy) (*n*=5), cake-like, round (*n*=3), drop-shaped (*n*=2), irregular shape (*n*=4) and cylindrical (*n*=7). The texture of the coprolites' surfaces varied from segmented surfaces to surfaces with cracks and, in one case, a smooth surface was observed. The categories observed in the Swifterbant-S4 coprolite assemblage mirrored some of the coprolite categories established for the S3 site. Also at S4, many faecal remains likely originated from animal (herbivorous) dung. Of these, five could be morphologically described, including

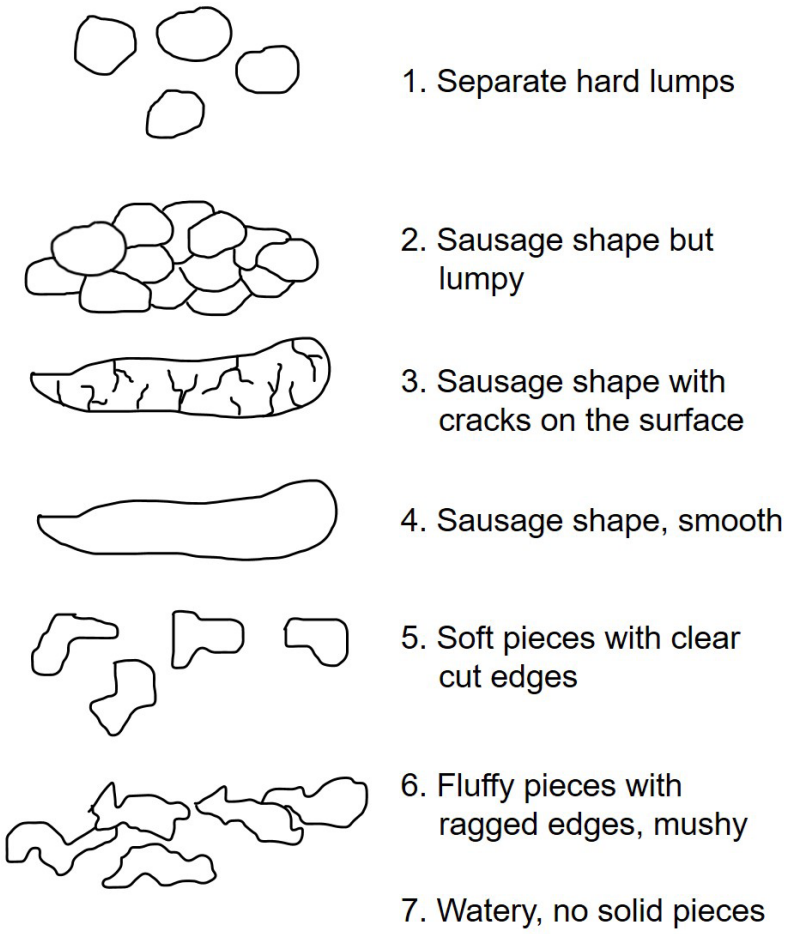


Figure 4.3 Bristol stool chart showing the variability of human faeces morphology in modern clinical contexts (adapted from Shillito *et al.* 2020).

sausage-like shape (*n*=1) and cylindrical shape (*n*=4). The two preserved coprolites from Emmeloord-J78-91 were morphologically classified as drop-shaped (*n*=1) and fluffy fragments with ragged edges (*n*=1). The coprolites from Hardinxveld-Giessendam De Bruin were described according to their morphological features as round-cylindrical (*n*=2) and multiple fluffy fragments with ragged edges (*n*=3).

As a result of this pre-selection phase, 42 coprolites representing various categories from the four sites were morphologically identified. In addition to the shape and the texture of the surface, the presence of animal and plant remains embedded in the outer surface was also observed and described - when it was absolutely clear that it was not non-faecal material that would have adhered to the surface prior to hardening and mineralisation. The colour of the

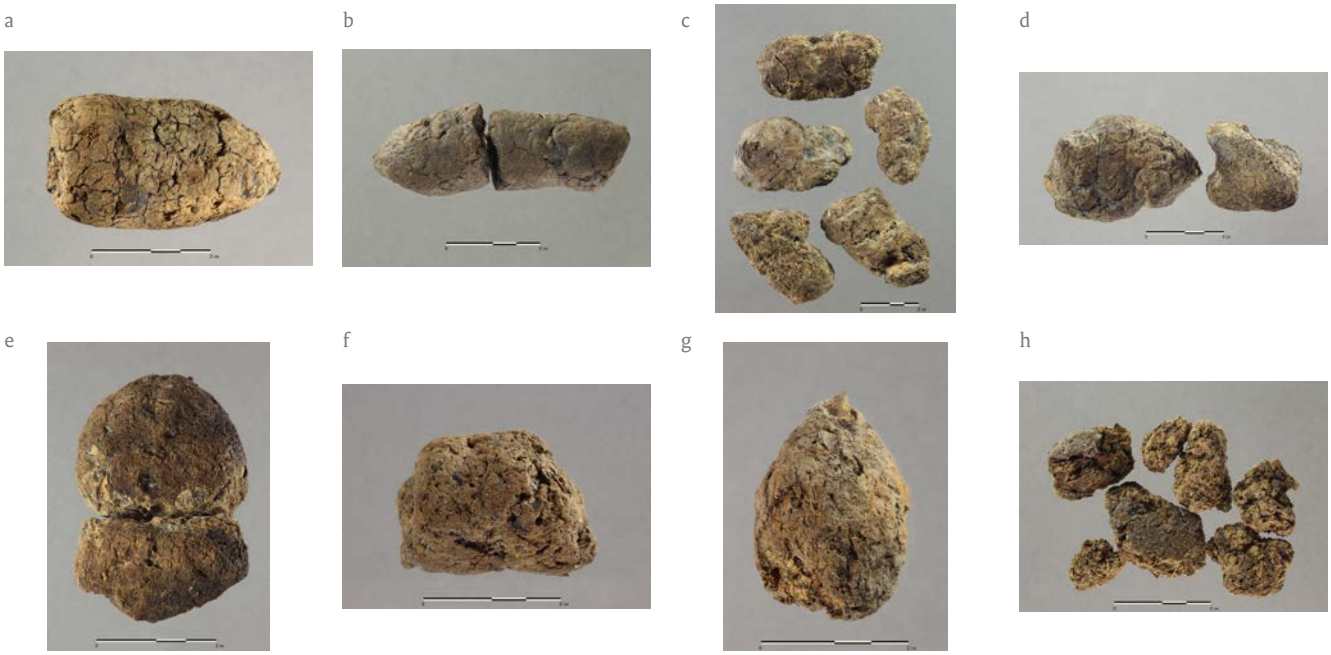


Figure 4.4 Examples of coprolites representing the different morphological categories defined for the studied sites. a. Sausage-like coprolite with cracks on the surface (S3-26), b. Sausage-like coprolite with a smooth surface (S3-13), c. and d. Separated lumps/pellets with a segmented surface (S3-15 and S3-4, respectively), e. Cake-like coprolite (S3-8), f. Cylindrical coprolite (S3-5), g. Drop-shaped coprolite (Emmeloord-J78-91, 1177), h. Multiple fluffy fragments with ragged edges (Hardinxveld-Giessendam De Bruin 19952).

coprolites varied from light to dark brown. All of the coprolites were odourless.

All of the morphological characteristics of these pre-selected 42 coprolites are described in Appendix I. Multiple specimens representative of each morphological category were selected for further analyses. This resulted in a series of 25 coprolites from four sites: Hardinxveld-Giessendam De Bruin (3 coprolites), Swifterbant-S3 (17 coprolites) and -S4 (3 coprolites), and Emmeloord-J78-91 (2 coprolites). A catalogue with detailed photographic images of these 25 coprolites is presented in Appendix II. Examples of the morphological categories are shown in Fig. 4.4. Some find numbers contain more than one specimen, but it is clear that they all belong to one act of defecation (for example, Fig. 4.4, C & H; see also Appendix II). For this study, the coprolites from the Swifterbant-S3 and -S4 received their coprolite code in correspondence with the sample number given during the excavations (see Appendix I and II).

4.4 Sampling for macrofossil and microfossil analyses based on initial lipid extractions

The selected 25 coprolites were subjected to GC-MS faecal lipid biomarker assessment to identify their faecal origin. According to the GC-MS assessment of the initial lipid extractions, there were some traces of possible bile acid compounds in several of the samples, suggesting a human or likely-human origin for eight coprolites and animal origin for three coprolites (including two pigs and one ruminant). The concentrations of lipids in the 14 other coprolites were too low to determine the producer organisms (see Table 4.1). Due to time constraints (related to covid-19), the tentative source identifications which were available were used to allow other multi-proxy analyses to be completed as part of this project, while the extraction and analysis of more lipids from additional sample material was continued. Unfortunately, even with this additional material, the concentrations from the combined

extracts were too low to detect sufficient bile acid compound concentrations in many of the samples by GC-MS analysis, thus explaining the number of coprolites that were finally attributed to an unconfirmed source (see Chapter 5). Even though the samples were run twice, and while some were initially classified as a 'best fit' for human origin on the assessment run, the sterol and bile acid concentrations were too low to give a firm species identification in the analysis phase (Chapter 5). Therefore, the lipid data/ratio calculations should be treated with caution. However, given the results from the multi-proxy analyses, the combination of data strongly suggests a human origin for many of the studied coprolites.

The explanation, perhaps, of the discrepancy between the assessment runs and the analysis phase lies in the possibility that different portions of coprolites were provided for each phase. Given the problems with low concentrations of faecal sterols, it might be more appropriate to assess this qualitatively using combined data.[105]

Based on the results of the initial GC-MS faecal lipid biomarker assessment, 13 coprolites were initially subjected to CT-scan and SEM analyses, including six coprolites of human origin (S3-2, S3-4, S3-10, S3-20, S3-28, S4-1) and two of likely-human origin (S3-15, S4-4), three coprolites of animal origin, including two pigs (Hardinxveld 19952, S3-18) and one ruminant (S3-5), and two coprolites of unknown source organism (S3-11 and S3-13). An additional three coprolites were added later to the CT-scan and SEM analyses, as we were intrigued by their morphology even though their faecal origin was not specified in the GC-MS assessment (Hardinxveld 19520, S3-8, and S3-26) (see Table 4.1).

A representative subsample was taken from each of the 13 coprolites for various microfossil analyses, including phytolith, pollen, intestinal parasite and starch analyses. Usually, half of the coprolite volume, and from some coprolites ¾ of the volume, was subsampled for SEM and microfossil analyses. In each case, a portion of the coprolite was preserved for future analysis, in case this should later be of scientific interest. During the subsampling for the SEM and microfossil analyses, the internal morphology of the coprolites was observed under the stereo microscope. Many coprolites contained charred particles of herbaceous tissues and some also contained charcoal fragments, implying absorption of charred plant particles while sitting or standing around the hearths or cooking fires, or introduction of ash and small pieces of charcoal to the cooking vessels during cooking, or eating from the ground (the latter would apply to coprolites with animal signal) (see Table 4.1). During the subsampling procedure for microfossil analysis, animal bone remains often fell out of the sampling portion of the coprolite matrices. They were later subjected to animal remains analysis (Chapter 7).

[105] Lisa-Maria Shillito & Helen Mackay, e-mail com. 6-09-2021.

Table 4.1. List of coprolites selected for macrofossil and microfossil analyses based on initial lipid extractions.

Site	Sample number	Coprolite code	Catalogue plate nr	Visual specimen description	Faecal steroids (1=assessment phase, 2=analysis phase, 3-revised)
Hardinxveld Giessendam -De Bruin (Provinciaal archeologisch depot Zuid-Holland)	7552	Hardinxveld 7552	I	One cylindrical coprolite with one end shaped by anus, fine matrix, no bone remains embedded but some hair (drilled hole left after subsampling for pollen analysis in 1998)	1. Indicates poor preservation so unable to determine source organism-2. n.d. = faecal steroids not detected
Hardinxveld Giessendam -De Bruin (Provinciaal archeologisch depot Zuid-Holland)	19520	Hardinxveld 19520	II	One ellipsoidal coprolite with cracks on the surface with small bone fragments embedded in fine matrix	1. Indicates poor preservation so unable to determine source organism-2. Not confirmed as faecal
Hardinxveld Giessendam -De Bruin (Provinciaal archeologisch depot Zuid-Holland)	19952	Hardinxveld 19952	III	Multiple fragments, fluffy pieces with ragged edges, many bone fragments embedded in the matrix, including fish scales	1. Likely pig -2. Pig
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54516	S3-2	IV	One large coprolite (in two pieces, reconstructed for photography), sausage-like shape, tapered at one end, rough surface, small and large bone fragments (including fish vertebrae) and plant tissue embedded in the matrix; also a few small burnt bones	1. Human -2. Pig
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54655	S3-4	V	Two coprolites, sausage-like shape but lumpy with characteristic cracks on the surface, one tapered at one end with small bone fragments embedded in the coprolite matrix	1. Human-2. Human-3.dog/human
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	51179	S3-5	VI	One coprolite, cylindrical, unsegmented. Rough surface. Small bone fragments embedded in the fine matrix	1. Unlikely human, bile acids suggest most likely ruminant-2. ?Ruminant
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	53985	S3-8	VII	One 'cake-like' coprolite, roundish-ellipsoidal, slightly flattened (now in two pieces). Fine bone fragments, fish scales, and plant tissue embedded in the matrix as well as a few charred bones	1. Indicates poor preservation so unable to determine source organism-2. Pig
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54845	S3-10	VIII	Three coprolites (one act of defecation), cylindrical, unsegmented. One of the coprolites tapered at one end. Seeds of Nymphaea alba (mainly seed testa remains) embedded in the matrix, also small and large bone fragments	1. Human-2. Human-3.dog/human
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54827	S3-11	IX	One coprolite (resembles finds from S3-10, sample number 54845), many seed fragments (testa remains) of Nymphaea alba embedded in coprolite matrix, also small and large bone fragments (including fish vertebra bones)	1. Indicates poor preservation so unable to determine source organism-2. Not confirmed as faecal
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	53842	S3-12	X	Two coprolite fragments (one act of defecation), sausage-like shape, tapered at one end, rough surface, with many small fish bones and plant tissue embedded in the matrix	1. Indicates poor preservation so unable to determine source organism-2. Not confirmed as faecal
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	53814	S3-13	XI	One coprolite (now in two pieces), sausage-like shape, smooth surface, tapered at one end, fine matrix, small and large bone fragments embedded in the matrix	1. Indicates poor preservation so unable to determine source organism-2. Unknown source-3. Unknown, possible carnivore
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	43716	S3-15	XII	Five large coprolites (most likely from one act of defecation). Separated lumps with a segmented surface (possibly originally sausage-shaped but lumpy). Described as 'mensen keutel' [human pellets] on the original bag. Small bone fragments and fish scales embedded in the matrices as well as some large bones	1. Likely human-2. Pig
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54752	S3-18	XIII	One coprolite with wrinkled surface and cracks, sausage-like shape, fine matrix, small bone fragments embedded in the matrix	1. 'Likely human and have good concentrations' in first round, while in second attempt 'likely pig', 2. in final results - n.d. faecal steroids not detected

CT-scan	Bone remains	SEM	Phytolith	Pollen and other microfossils	Helminths	Starch granules
no data	no data	no data	no data	no data	no data	no data
x	x	x	no data	no data	no data	no data
x	x	x	x	x	x	x
x	x	x	x	x	no data	x
x	x	x	x	x	x	x
x	x	x	x	x	no data	x
x	x	x	no data	no data	no data	no data
x	x	x	x	x	x	x
x	no data	x	x	x	x	x
	x	x	no data	no data	no data	no data
x		x	x	x	x	x
x	x	x	x	x	no data	x
x	x	x	x	x	no data	x

Site	Sample number	Coprolite code	Catalogue plate nr	Visual specimen description	Faecal steroids (1=assessment phase, 2=analysis phase, 3-revised)
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	57328	S3-19	XIV	One coprolite, cylindrical, small bones embedded in fine matrix	1. Indicates poor preservation so unable to determine source organism-2. n.d. = faecal steroids not detected.
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	57443	S3-20	XV	Two coprolites (most likely from one act of defecation), sausage-like shape, surface with cracks, fine matrix, bone (including fish vertebrae) and plant tissue embedded in the matrix. A few charred bones embedded in the matrix	1. Human-2. Human
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54240	S3-23	XVI	One coprolite, cylindrical, rather smooth surface, fine matrix, small bone fragments embedded in coprolite matrix	1. Indicates poor preservation so unable to determine source organism-2. n.d. = faecal steroids not detected
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	53954	S3-26	XVII	One coprolite, sausage-like, rather smooth surface with some cracks, tapered at one end, small and large bone fragments embedded in fine matrix	1. Indicates poor preservation so unable to determine source organism-2. Human-3. dog/human
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54052	S3-27	XVIII	One coprolite fragment, small bone fragments and plant tissue embedded in the matrix.	1. Indicates poor preservation so unable to determine source organism-2. n.d = faecal steroids not detected
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	54488	S3-28	XIX	Three coprolites, separated hard lumps from likely one act of defecation, characteristic cracks on the surface. Fish scales and a few small bone fragments embedded in coprolite matrices. Possible plant tissue. Fine matrix	1. Human-2. Unknown (human/ ruminant)
Swifterbant S3 (excavation 1976-1977). Provinciaal Depot Flevoland, Lelystad (Box nr 413, L=558)	45691	S3-29	XX	One coprolite fragment, cylindrical, irregular shape, some cracks on the surface, small and large bone fragments embedded in coprolite matrix, fish vertebrae, also plant tissue.	1. Indicates poor preservation so unable to determine source organism-2. n.d = faecal steroids not detected
Swifterbant S4 (excavation 1974). Provinciaal Depot Flevoland, Lelystad (Box nr. 269)	1420	S4-1	XXI	Three coprolites (one act of defecation), sausage-like shape, rough surface, very fragile/brittle, many small bone fragments embedded in coprolite matrix, including fish vertebra bones	1. Human-2. n.d. = faecal steroids not detected
Swifterbant S4 (excavation 1974). Provinciaal Depot Flevoland, Lelystad (Box nr. 269)	1366	S4-3	XXII	One coprolite fragment, cylindrical with fine matrix, some small bone fragments embedded in the matrix, rather smooth surface	1. Indicates poor preservation so unable to determine source organism-2. n.d. = faecal steroids not detected
Swifterbant S4 (excavation 1974). Provinciaal Depot Flevoland, Lelystad (Box nr. 269)	629	S4-4	XXIII	One coprolite fragment with fine matrix, cylindrical, flattened, small bone fragments embedded in the matrix	1. Likely human-2. n.d. = faecal steroids not detected
Emmeloord-J78-91. Provinciaal Depot Flevoland, Lelystad (Box nr 685)	1177	J78 91-2	XXIV	One teardrop-shaped coprolite, tapered on one end, many fish bones embedded in the matrix	1. Indicates poor preservation so unable to determine source organism-2. not confirmed as faecal
Emmeloord-J78-91. Provinciaal Depot Flevoland, Lelystad (Box nr 685)	1184	J78 91-1	XXV	Two coprolite fragments (one act of defecation), rough surface, large fish bones embedded in the matrix (one of the two specimens photographed)	1. Indicates poor preservation so unable to determine source organism-2. n.d. = faecal steroids not detected.

CT-scan	Bone remains	SEM	Phytolith	Pollen and other microfossils	Helminths	Starch granules
no data	no data	no data	no data	no data	no data	no data
x	x	x	x	x	no data	x
no data	no data	no data	no data	no data	no data	no data
x	x	x	no data	no data	no data	no data
no data	no data	no data	no data	no data	no data	no data
x	x	x	x	x	x	x
no data	no data	no data	no data	no data	no data	no data
x	x	x	x	x	x	x
no data	no data	no data	no data	no data	no data	no data
x	no data	x	x	x	x	x
no data	no data	no data	no data	no data	no data	no data
no data	no data	no data	no data	no data	no data	no data

5 Faecal steroid lipid biomarkers

H. Mackay

5.1 Introduction

The identification and characterisation of coprolitic material can be achieved using faecal lipid biomarkers. 5β-stanol and bile acids are two classes of lipid compounds that are preserved within coprolites and are diagnostic of the producer organism owing to species-specific differences in food sources, digestive processes and gut bacteria.[106] Here we applied faecal lipid biomarker analysis to confirm and identify the faecal origin of 25 coprolite samples obtained from four sites: Hardinxveld-Giessendam De Bruin, Swifterbant-S3 and -S4, and Emmeloord-J78-91.

5.2 Methods

Subsamples for faecal steroid analyses were obtained from 25 coprolites (Table 5.1). The exterior of each coprolite was removed by a solvent-cleaned scalpel to ensure that only central material of each coprolite was sampled for steroid analysis, thereby minimising environmental contamination. Sterols and bile acids were analysed from each sample following the protocol outlined in Mackay *et al.*[107] Briefly, lipids from c. 1.5 g of each coprolite subsample was solvent extracted (DCM:MeOH, 2:1, v/v) using microwaved assisted extraction. Lipid extracts were saponified (using 5 M NaOH) and separated into sterol and bile acid fractions using silica gel column chromatography. Once trimethylsilylated, the sterol and bile acid fractions were analysed by gas chromatography mass spectrometry (GC-MS).

The presence of coprolitic material and the producer organisms are identified based on diagnostic compounds ratios, four of which are applied with this report:[108]

1. Presence of faecal matter:[109] (coprostanol+epicoprostanol)/(5α-cholestanol+coprostanol+epicoprostanol), where values >0.3 indicate possible faecal matter input.
2. Differentiation between herbivore, pig and human faeces:[110] (coprostanol/(coprostanol+5β-stigmastanol)) x 100, where values <29% with no hyodeoxycholic acid (HDCA) indicate herbivore; 29-65% with HDCA indicate pig; and >65% with chenodeoxycholic acid (CDCA) and no HDCA indicate human sources.
3. Differentiation between pigs and/or geese, humans and/or horses and ruminants:[111] deoxycholic acid (DCA)/lithocholic acid (LCA), where values <0.4 indicate pigs and/or geese; 0.6-4.5 indicate human and/or horses; and >5 indicate cattle, sheep and/or goats.
4. Differentiation between humans and carnivores (often attributed to canines): coprostanol/cholesterol, where values <1 with a predominance of DCA and a higher proportion of cholic acid (CA) indicate carnivore faecal sources.[112]

5.3 Results and discussion

5.3.1 Preservation of faecal steroids

The preservation of target faecal steroid compounds is variable between samples. Only three of the confirmed faecal samples contained detectable concentrations of all steroid compounds required for the four diagnostic ratios (Table 5.1). Furthermore, lithocholic acid (LCA) and deoxycholic acid (DCA) were the only detectable bile acids in the samples analysed. The low rates of steroid preservation in the samples analysed in this study have resulted in a high number of unconfirmed coprolites: ten out of the 25 samples have undetectable levels of any steroid compounds (indicated by n.d. in Table 5.1) and the inconclusive source of three of the confirmed coprolites (Table 5.1).

5.3.2 Faecal origins of samples

Thirteen samples analysed in this study contained detectable 5α-stanols and 5β-stanols and eight contained detectable bile acids (Table 5.1). Four samples contained Ratio 1 values <0.3 and no bile acids, indicating that they are unlikely to be of faecal origin, whilst nine samples were confirmed to be of faecal origin (Table 5.1, Fig. 5.1). The abundances of faecal steroid compounds were variable

[106] Bull, Evershed & Betancourt 2002; Prost *et al.* 2017.
[107] Mackay *et al.* 2020.
[108] Bull, Evershed & Betancourt 2002; Prost *et al.* 2017.
[109] Bull, Betancourt & Evershed 1999; Prost *et al.* 2017.
[110] Prost *et al.* 2017.
[111] Prost *et al.* 2017.
[112] Shillito *et al.* 2020a.

Table 5.1 Summary of faecal steroid data from coprolites analysed within this study.

Lipid extraction no.	Sample number	Coprolite code	Ratio 1	Ratio 2	Ratio 3	Ratio 4	Faecal summary
326	7552	Hardinxveld 7552					n.d
327	19520	Hardinxveld 19520	0,04				not confirmed as faecal
328	19952	Hardinxveld 19952	0,85		0,33	4,51	pig
329	54516	S3-2	0,78		0,4	2,04	pig
330	54655	S3-4	0,57		3,77	0,18	carnivore*/human
331	51179	S3-5			5,78		ruminant?
332	53985	S3-8			0,22	1,5	pig
333	54845	S3-10	0,49	95,7	1,44	0,84	carnivore*/human
334	54827	S3-11	0,08				not confirmed as faecal
335	53842	S3-12	0,14				not confirmed as faecal
336	43716	S3-15	0,59	52		0,28	pig
337	53814	S3-13	0,79			0,4	unknown, possible carnivore
338	54752	S3-18					n.d
339	57328	S3-19					n.d
340	57443	S3-20	0,65		0,92	1,42	human
341	54240	S3-23					n.d
342	53954	S3-26	0,33	85,7		0,72	carnivore/human
343	54052	S3-27					n.d
344	54488	S3-28	0,93	90,9	22	24,26	unknown (human/ ruminant)
345	45691	S3-29					n.d
346	1420	S4-1					n.d
347	1366	S4-3					n.d
348	629	S4-4					n.d
349	1184	Emmeloord-J78-91-1					n.d
350	1177	Emmeloord-J78-91-2	0,13				not confirmed as faecal

Ratio 1 values >0.3 represent possible faecal matter (orange). Producer organism of samples with those with confirmed faecal matter (orange) can be identified using Ratio 2 (<29% = herbivore, 29-65% = pig, >65% = human), Ratio 3 (<0.4 = pigs and/or geese; 0.6-4.5 = human and/or horses; >5 = ruminant) and Ratio 4 (<1 = possible carnivore since there was no cholic acid present to confirm this identification. Carnivore* indicates likely carnivore source owing to predominance of DCA). N.d. = faecal steroids not detected. Full details of each ratio are provided in section 5.2 of this chapter.

between samples and not all had sufficient concentrations to test Ratio 2, Ratio 3 and Ratio 4 values. However, the available data for the confirmed faecal samples indicates that four samples originated from porcine sources (Hardinxveld-Giessendam De Bruin 19952, S3-2, S3-8 and S3-15, one sample was confirmed as human faeces (S3-20) and three samples originated from either carnivorous sources such as canines or humans (S3-4, S3-10 and S3-26, although two of these samples, S3-4 and S3-10, have DCA values that are more likely indicative of a canine source (Fig. 5.1, Table 5.1). Two samples, S3-5 and S3-28, have inconclusive steroid ratios but possibly originated from ruminant species, although the latter sample could also be of human origin. There is insufficient information to identify the producer

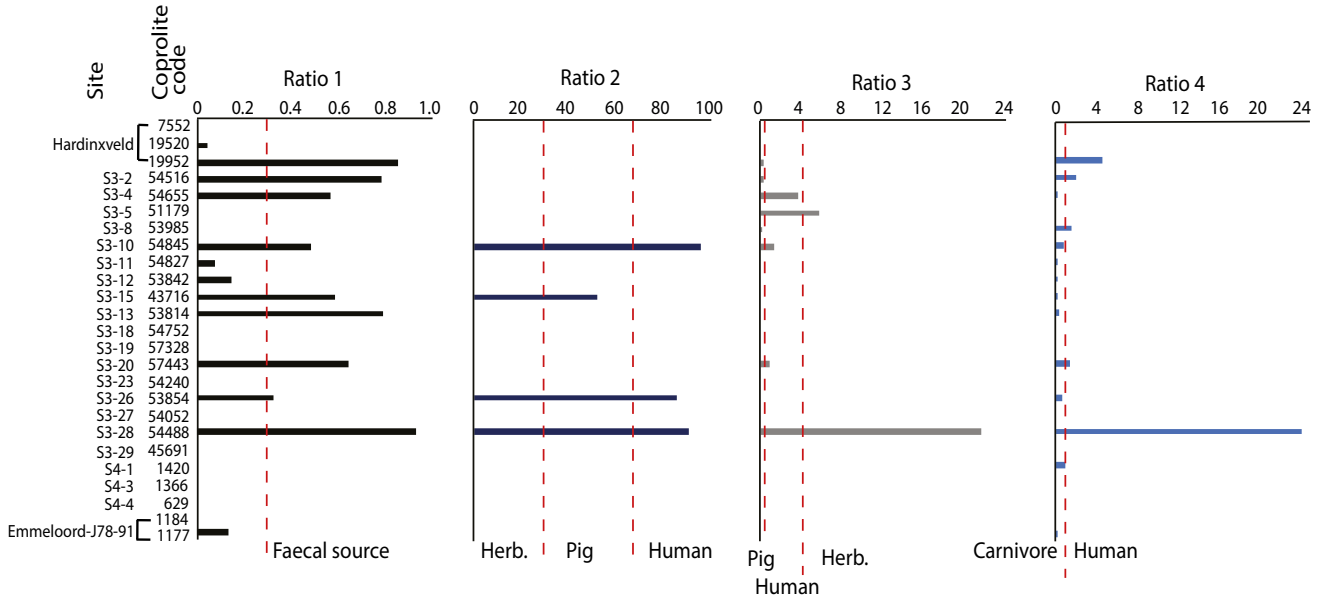


Figure 5.1 Summary of faecal steroid results. Ratio 1 values >0.3 (dashed red line) indicate possible faecal sources; Ratio 2 values <29% indicate herbivore dung (strong red dashed line), 29-65% indicate pig faeces (faint red dashed line) and >65% indicate human faeces; Ratio 3 values <0.4 indicate pigs and/or geese (strong red dashed line), 0.6-4.5 indicate human and/or horses (faint red dashed line) and >5 indicate a ruminant source; and Ratio 4 values <1 (faint red dashed-line) indicate a possible carnivore source. The absence of detected cholic acid precludes confirmation of carnivore faeces but the predominance of DCA in samples [S3-4 54655] and [S3-10 54845] indicates that a carnivorous source, often attributed to canines, is likely. Full details of each ratio are provided in section 5.2 of this report.

organism of sample S3-13 (Table 5.1). The animal assemblage characterised by this study based on steroid-inferred coprolitic sources is typical of Swifterbant sites: for example, faunal analyses from three sites in Eastern Flevoland were dominated by pig remains, with lesser contributions from cattle and sheep/goat.[113]

5.3.3 Spatial patterns of producer organisms

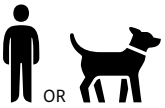
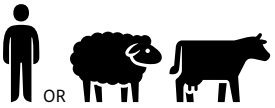
Samples analysed from Hardinxveld-Giessendam De Bruin and Swifterbant-S3 were a mix of faecal and unconfirmed faecal sources: one out of the three samples analysed from Hardinxveld-Giessendam De Bruin is confirmed as porcine in origin and seven out of the 17 samples analysed from Swifterbant-S3 are confirmed to be of porcine, canine and human origin. No samples analysed in this study from sites Swifterbant-S4 and Emmeloord-J78-91 yielded sufficient steroid concentrations to confirm that the samples were of faecal origin.

5.4 Conclusions

All confirmed coprolites in this study originated from Hardinxveld-Giessendam De Bruin and Swifterbant-S3 sites (Table 5.2). Pigs, humans and other carnivores (likely canines) were the dominant producer organisms of the confirmed coprolites, accounting for nine of the eleven confirmed coprolites (Table 5.2). The absence of detected cholic acid precludes a firm identification of carnivorous faecal sources, however two samples contain a predominance of DCA indicating that a more carnivorous source, such as canine, is likely. Two of the eleven confirmed faecal samples may have originated from ruminant sources (cattle and/or sheep/goat), however, the preservation of faecal steroid compounds in these samples is insufficient to facilitate confirmation of ruminant sources. The steroid-inferred animal assemblage characterised in this study is a typical Swifterbant pig-dominated assemblage.

[113] Zeiler 1997.

Table 5.2 Visual summary of coprolite likely producer organism based on faecal steroid analyses.

Lipid extraction number	Sample number	Coprolite code	Producer organism
328	19952	Hardinxveld 19952	
329	54516	S3-2	
330	54655	S3-4	
331	51179	S3-5	
332	53985	S3-8	
333	54845	S3-10	
336	43716	S3-15	
337	53814	S3-13	 possible
340	57443	S3-20	
342	53954	S3-26	 OR
344	54488	S3-28	 OR

6 Micro-CT scanning analysis

D. Ngan-Tillard & J. Zeiler

6.1 Introduction

In recent years, several researchers have illustrated the potential of X-ray micro-computed tomography (micro-CT) in the study of archaeological soils and artefacts. Hunt *et al.*, Huisman *et al.*, Wang *et al.*, Qvarnström *et al.*, and Shillito *et al.* have already foreseen and even demonstrated the added value of the technique for the investigation of ancient coprolites.[114] Coprolites contain partially digested macro-food remains which can be distinguished on a micro-CT scan when they are large enough and contrast sufficiently in terms of X-ray attenuation values and/or patterns with the faecal mass. The scans of coprolites provide a direct and non-destructive way to assess diets from the past.

The non-invasive see-through capacity (visually penetrating capacity) of a micro-CT scanner can be used in the study of coprolites for multiple purposes, for example to:

- digitally record the 3D morphology and surface roughness of the whole coprolite before it is damaged due to subsampling;
- visualise in 3D the leftover food ingredients that were ingested but not fully digested such as entire and fragmented bones and plant tissues;
- contribute to the identification of certain remains at the kingdom to species level based on 3D surface and/or inner structure;
- cross-check or complement results of archaeobotanical and zoological analyses on macroremains;
- reveal the spatial organisation of macroremains in the coprolite and disclose links between fragments which are separated during traditional sieving analysis;
- highlight the degree of material degradation, fragmentation and mineralisation;
- screen coprolites and discard badly preserved samples;
- optimise the subsampling of individual coprolites for subsequent analyses and guide the micro-excavation of macroremains for detailed analysis.

While the studies cited above focused on the micro-CT scans of a small number of often disparate coprolites, our investigation concerns a large group, 16 coprolites in total, recovered from Hardinxveld-Giessendam De Bruin (Late Mesolithic – Early Neolithic) and Swifterbant-S3 and -S4 (Early Neolithic) sites. Several of these coprolites have been indicated (in the initial lipid extractions) to be or are likely to be of human origin (see Chapter 4). Shillito *et al.* displayed scans of human coprolites in their 2020 state-of-the-art article on the analysis of coprolites in archaeology without fully exploiting the information contained within the scans.[115] Botanical remains entrapped in faecal masses have received very little or no attention in published micro-CT analyses of coprolites, partly because some of the scanned coprolites were produced by carnivores, insectivores or aquatic predators preying on shellfish and fish, and partly because plant remains are more difficult to extract than bones as they contrast less with the faecal mass. Plant tissues might have been degraded and distorted by digestive and soil processes to such an extent that none of their taxa could be determined. The present study revealed some facets of the vegetative ingredients in the Neolithic diet by following the approach adopted in Barron & Denham, and Kozatsas *et al.* to distinguish organic temper used in the production of ceramics from plant phantoms.[116] We tracked the impressions that plant parts (seeds, stems, branches) left in the faecal mass once the plant parts themselves had vanished. We also searched for plant tissues that would have withstood (possible) cooking, ingestion, digestion, soil processes and archaeological excavation works as well as storage in dry conditions in archaeological depots.

Micro-CT scans were made of a set of coprolites to investigate the diversity of human diet at the Swifterbant sites, determining the types of ingredients combined in one meal or at least ingested in a period of a few days to gain knowledge on cooking and eating habits of the Swifterbant Culture.

In the following sections of this chapter, we justify the strategy we adopted to select the coprolites that were subjected to micro-CT scanning. Then, we briefly present the principle of micro-CT scanning and explain how to read the scan of a coprolite. We also discuss the equipment we used to scan the coprolites and produce 3D-printed replicas of ecofacts (plant and animal tissues) extracted from the digital coprolites.

[114] Hunt *et al.* 2012; Huisman *et al.* 2014; Wang *et al.* 2018; Qvarnström *et al.* 2017; Shillito *et al.* 2020a.
[115] Shillito *et al.* 2020a.
[116] Barron & Denham 2018; Kozatsas *et al.* 2018.

6.2 Material

Based on the results of the GC-MS faecal lipid biomarker assessment, 13 coprolites were initially subjected to micro-CT analysis. Of these, six coprolites were attributed to human (S3-2, S3-4, S3-10, S3-20, S3-28, S4-1) and two to likely-human origin (S3-15, S4-4). Furthermore, three coprolites identified as of animal origin, including two pigs (Hardinxveld-19952, S3-18) and one ruminant (S3-5), and two coprolites of unknown producer organism (S3-11 and S3-13) were selected for micro-CT-scan analysis. An additional three coprolites were added later to the CT-scan (and SEM analysis), as their morphology was rather intriguing, even though their faecal origin was not specified in the GC-MS assessment (Hardinxveld 19520, S3-8 and S3-26) (Chapter 4, Table 4.1).

The three animal coprolites stand out from the rest of the group by their shape or texture and were selected to explore the difference with coprolites indicated as human in the GC-MS assessment : Hardinxveld-19952 is segmented in three fragments of less than 1 cm3 and looks like dung. S3-18 has a smooth surface. The coprolites of unknown origin are all, except S3-8, sub-rounded; they are assumed to have an omnivore as a source origin. S3-8 is a flat, rounded (cake-like shaped) coprolite.

6.3 Methods

6.3.1 Equipment: Micro-CT scanner principle and apparatus

On a micro-CT scan, a coprolite appears as an amorphous matrix containing a number of inclusions that more or less attenuate the X-ray (Fig. 6.1). The brighter the colour, the more the material attenuates the X-ray. Bones are rich in phosphorus and calcium. These chemical elements have a relatively high atomic number compared to carbon, the main element of organic compounds (excluding bones and shell-like materials). This is why, according to Beer's law of attenuation for X-ray attenuation, bones embedded within a faecal matrix appear as white inclusions in a darker background. From bright to

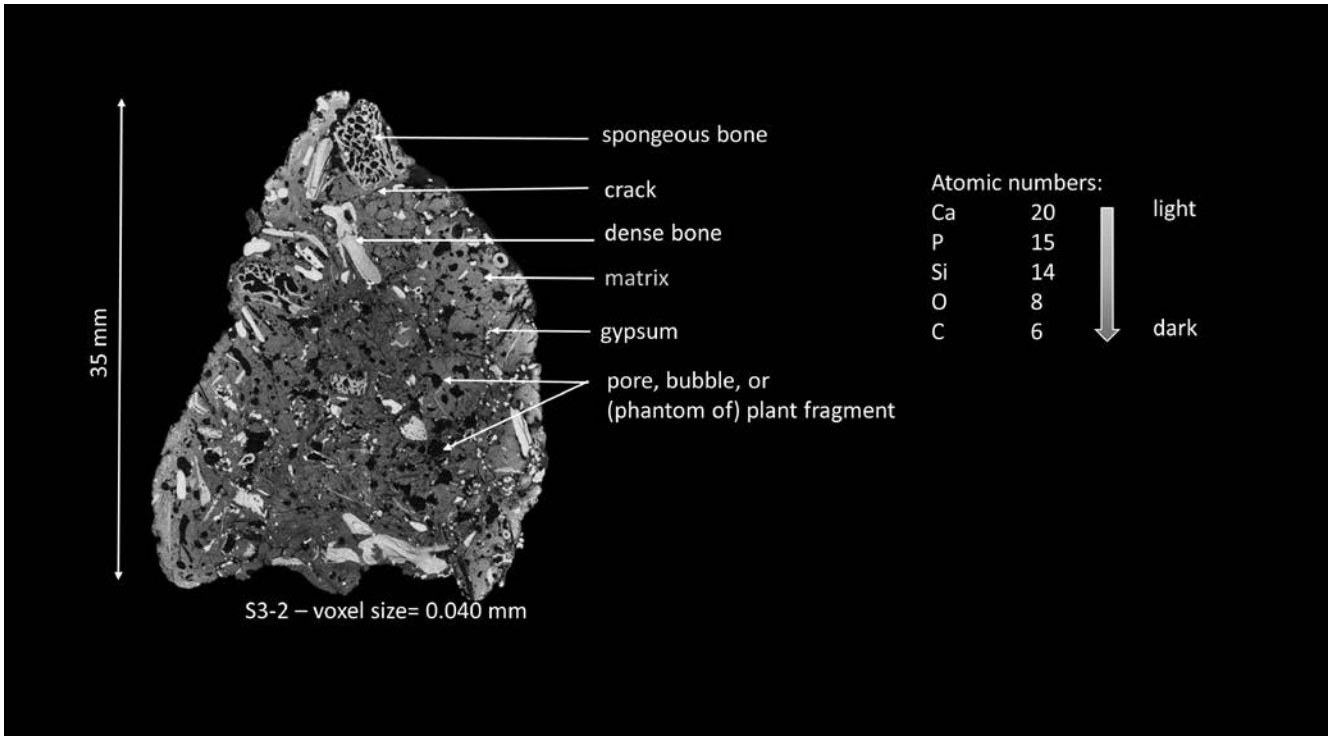


Figure 6.1 Decoding a vertical slice extracted from the micro-CT scan of coprolite S3-2. The grey value of each pixel represents the local X-ray absorption of the material. The higher the X-ray absorption of the material, the whiter the pixel. Materials with high density or high atomic numbers attenuate X-rays the most.

dark, the following items can be distinguished in the scan: gypsum mineralisation, bones, matrix and plant remains, and voids. Phantoms of plant remains, cracks and bubbles are the darkest. As the whole domain which is scanned (including the empty space surrounding the coprolite) is affected by noise, voids do not show up as fully black. Because of X-ray artefacts that cannot be perfectly corrected for heterogeneous objects of irregular shape, the summit and concave edges of the coprolite can appear whiter than the rest of the coprolite. This does not mean that they are denser. Moreover, some bones have degraded by leaching and/or become more porous; they show up with a darker colour and this complicates their digital extraction.

X-ray micro-CT can reveal the contents of a coprolite to a degree of detail that depends on the type of scanner used and the size of the coprolite scanned. Advances in hardware and software allow reliable reconstruction of a region of interest within a coprolite at a higher resolution. The rule of thumb remains the same: the voxel size of the 3D model is about 1/1000 the width of the object or region of interest scanned with the lower limit set by the spot size and penetration power of the micro-CT. A voxel size of 0.020 to 0.040 mm is commonly achieved for the scan of an entire human coprolite using a desktop micro-CT scanner. Subscans of coprolite tips, fragments, or targeted zones within the core of a coprolite with a voxel size below 0.010 mm are necessary to image remains of millimetre and sub-millimetre size in great detail. It should be remembered that the spatial resolution is never as good as the voxel size because of the noise inherent to micro-CT.

The set of coprolites selected for this study was scanned at the Faculty of Civil Engineering and Geosciences in Delft with a Nanotom X-ray micro-CT scanner manufactured by General Electric. A drawing of the micro-CT scanner set-up is shown in Fig. 6.2. The coprolites were glued onto a wooden rod which was then clamped in the rotation platform of the scanner. This prevented the relative movement of the lightweight coprolites concerning its base support during data acquisition and avoided X-ray diffraction from the steel rotation platform. Scans of the whole coprolites were acquired with a 0.010 to 0.020 mm voxel size and reconstructions were done with a 0.020 to 0.040 mm voxel size to reduce the data set size to less than 1.5 GB per scan and filter out noise

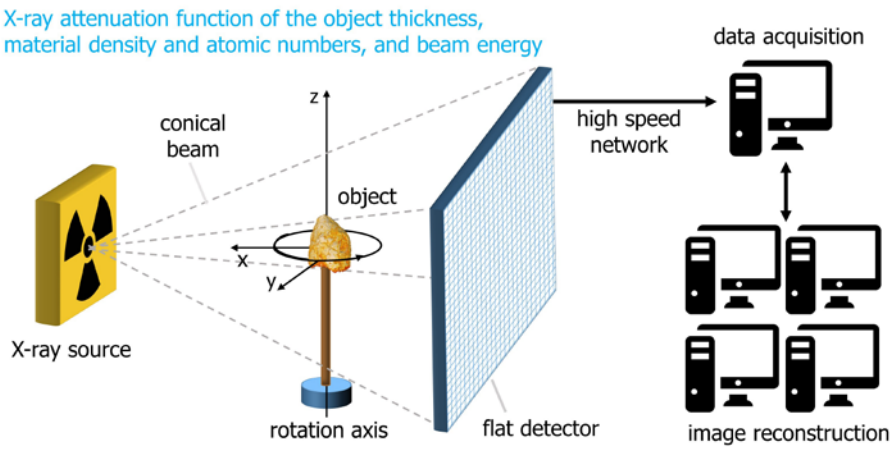


Figure 2: micro-CT scanner set-up

Figure 6.2 Micro-CT scanner set-up. X-rays are generated in an X-ray source and travel through the sample fixed onto a rotational stage. Some are absorbed or scattered by the material and do not reach the flat X-ray detector. Others are transmitted and are recorded by the detector as a 2D radiograph. The number of transmitted X-ray depends on the thickness, density and the atomic number of the material, and the energy of the X-ray beam. The sample is rotated a fraction of a degree on the rotational stage, and another radiograph is taken. This step is repeated through a full rotation of the sample. The series of radiographs are then processed to reconstruct the scanned sample as a 3D matrix of voxels (volumetric pixels). Slices can be extracted from the 3D reconstructed sample, analyzed, and further processed into 3D models. The models can be made into movies and 3D-printed.

at the same time. Beam hardening was corrected for during reconstruction based on standard backpropagation algorithms. Subscans of coprolite tips, fragments, and regions of interest within the coprolites were also acquired with a voxel size of 0.0055 to 0.010 mm and reconstructed at double voxel size. See Appendix III (Table III. 1) for the scan parameters and Ngan-Tillard *et al.* for the methodology.[117]

Observations using a stereomicroscope (Chapter 4) were made on the surface of the coprolites, as well as using the SEM (Chapter 8) to help to identify the signature of given remains on the micro-CT scans. Replicas of bones and plant remains were created using stereolithography with a Form2 3D printer manufactured by Formlabs. Stereolithography uses a liquid photopolymer that is selectively cured by a laser.

6.3.2 Processing

The data was processed using commercial image analysis software (AVIZO versions 2019.1 to 2020.2). Scans were denoised using non-local means of filtering. A 3D volume rendering set at low transparency was used to rapidly visualise the morphology of the coprolites. The coprolites were then virtually sectioned into three orthogonal slices to explore their inner structure. The multi-directional cuts helped to identify remains with a peculiar morphology.

The volume of bones was obtained by interactive thresholding. The high threshold value was chosen to separate bone from gypsum mineralisation which is characterised by a very high attenuation coefficient and the low threshold value, to separate bone from the faecal matrix. Neither threshold allowed a neat segmentation of the bone volume. Some weathered bone parts only slightly attenuated the X-ray and were excluded from the selection. Other parts were mineralised and attenuated the X-ray as much as gypsum crystals do and were also excluded. In some cases, a sequence of gentle erosion, filtering and dilatation was applied to better isolate the bones. In most cases, this would not have been sufficient and was thus not performed since some thin bone material would disappear in the process. Instead, bone volumes were selected using a broad range of grey values. The bone surfaces were then meshed with a low constrained smoothing factor and imported into the open source software MeshLab for digital cleaning. Contacts between bone and parasite volumes (i.e. volumes not belonging to bone) were aligned vertically or horizontally and carefully sectioned. This created some holes in the bone surfaces; the smallest holes were closed in MeshLab, and the largest were repaired with the 3D printing software (Preform). Bones were grouped (teeth and spines, vertebrae, scales, etc.) in MeshLab. After the cleaning operation, the different groups of bone surfaces were superimposed onto the grey images in AVIZO and a colour was attributed to each group. The overlaying allowed the evaluation of the accuracy of the bone surface representation and the identification of bone parts missed during the processing. It also determined the inner structure of the bones. The results were recorded on videos.

More advanced filters based on membrane enhancement, structure enhancement or texture classification principles were tested. The results were only convincing for trivial cases. As a consequence, bone extraction became a time-consuming process requiring digital cut-up. A small number of fish bones formally identified during the traditional archaeo-zoological analysis were also scanned to serve as digital reference material (Fig. 6.3).

The extraction of the botanical content required additional steps. Ambient occlusion was applied onto the volume of bone and matrix to

[117] Ngan-Tillard *et al.* 2018.

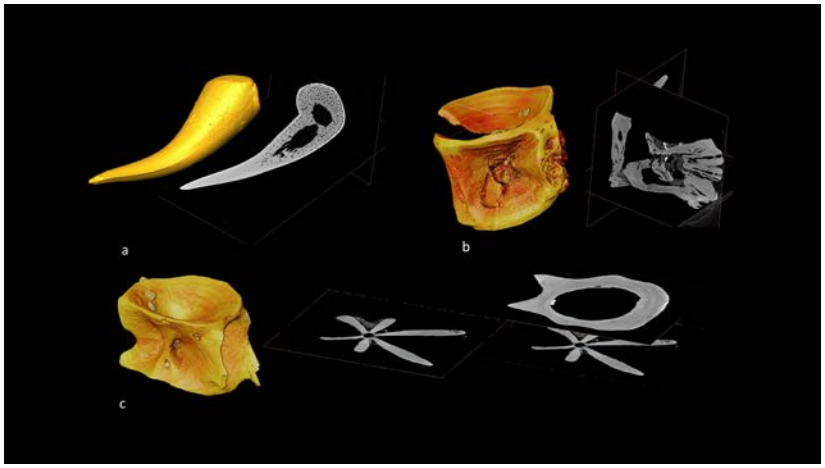


Figure 6.3 Digital reference bone morphologies and anatomies. a. Pike tooth, 5.1 mm long; b. Pike vertebra, 4.6 mm high; and c. cyprinid vertebra, 2.8 mm high. The tooth and the vertebrae were physically extracted from coprolites S3-18 and S3-20, respectively.

detach the low attenuating materials and inner voids from the outer space without losing low attenuating objects which outcrop at the surface of the coprolite.[118] Where thick gypsum mineralisation lined the phantoms of seeds, the volume of gypsum was thresholded and merged with that of low attenuation material. The addition of both volumes (bone plus matrix and low attenuating material) provided the total volume of the coprolite and was used to mask the coprolite and filter from the noisy background.

In general, plant tissues and phantoms of plant tissues are more challenging to the 3D image than bones due to the similar X-ray attenuation coefficients they present with cracks, bubbles, inner cavities in bones and even weathered bone material. Often, the surface of the connected low attenuating material occupies 2 to 3 GB. It is too large to be cleaned quickly in MeshLab. Therefore, the first step of the separation process was applied to regions of interest bordering the targeted tissues. Those were detected by sliding a slice across the coprolite or clipping the 3D representation of the low attenuating material with a slice and sliding this slice, now made invisible, across the coprolite together with a grey slice placed at a distance of 1 or 2 mm ahead of it. This later slice was made visible and allowed some in-depth viewing through the dense network of low attenuating material.

6.4 Results

Scans highlight similarities and differences between coprolites in terms of shape, surface, structure, degree of mineralisation, macroremains content and composition. The list of scans and subscans can be found in Appendix III. Catalogues presenting the morphology, fabric, bone and plant content of each coprolite are provided as supplementary material in Appendices IV to VI. Videos produced from the scans can be downloaded via a TU Delft SurfDrive link given in Appendix III.

6.4.1 Morphology

The 3D volume rendering allowed the visualisation of the shape and surface roughness

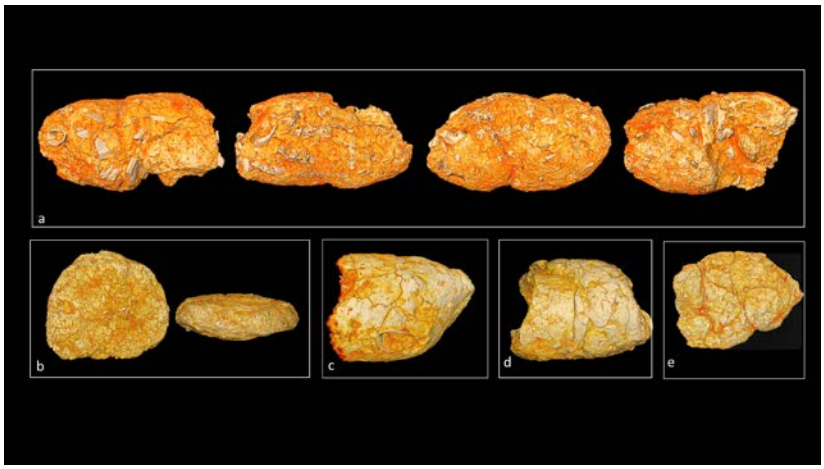


Figure 6.4 Micro-CT scans of selected coprolites from Swifterbant-S3. a. S3-20, sausage-shaped coprolite with surface marks left by intestinal contractions commonly observed on human coprolites; b. S3-8, rounded cake-like coprolite; c. S3-13, coprolite with smooth surface; d. S3-18; and e. S3-4: surface marks left by intestinal contractions. Many large bones protrude from the surface of S3-20, and a few to several at the surface of S3-8 and S3-18. Mainly small bones are visible on the surface of S3-4.

of the coprolites (Fig. 6.4). For example, it helped to distinguish coprolites with a smooth outer surface which are less likely to be of human origin. It also underlined surface marks left by intestinal contractions which are commonly observed on human coprolites. These morphological features were used at the beginning of the material selection phase of our study (Chapter 4). They are now digitally recorded in the scans and are available for future morphometric analyses in the interests of science, even if the coprolites have been destroyed in the process of subsampling for further analyses.

In addition, 3D volume rendering accentuated outcropping bones, which can greatly accelerate inspection under the binocular light microscope.

6.4.2 General characteristics

In general, one vertical cross-section sufficed to describe the general characteristics (fabric) of the coprolites, including the degree of weathering, mineralisation and fragmentation (Fig. 6.5). All coprolites consist of an amorphous matrix with various types and sizes of macroremains and other inclusions. The resolution of the scans precluded the possibility to discern micro-remains (phytoliths, pollen and

[118] Titschack *et al.* 2018.

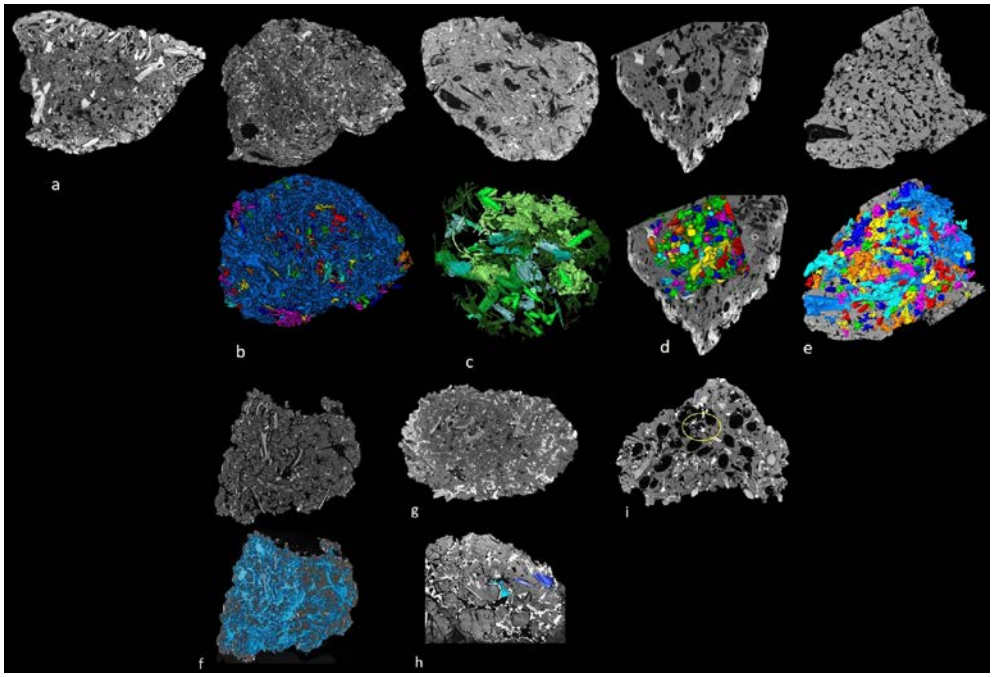


Figure 6.5 Various types and material fabrics, porosities and degradation. Inner structure dominated by a. large bones (S3-2); and b. thin, elongated plant-like remains plus some small bones (S4-1). Network of c. sub-rounded (S3-18) and d. angular (Hardinxveld-19520) macro-pores; e. Extensive fracturation (Hardinxveld-19952); f. Gypsum mineralisation penetrating deep inside coprolite S4-1; g. Zoom showing continuous gypsum mineralisation filling in cracks or gaps between bones (in color) and matrix and coating cavities (S3-15);h. Numerous acicular gypsum mineralisations in phantoms of lily seeds (S3-11). Desiccation cracks are visible at the surface of many coprolites, especially in the coprolites featured in d, e, and g.

parasite eggs) and micro-porosity. Macro-porosity varies from rounded bubbles to angular voids, with or without a polygonal desiccation crack pattern. Cylindrical, discoidal, spherical, or ellipsoidal forms were presumably formerly occupied by stems or seeds. These are discussed in the section on SEM analysis (Chapter 8). Inner cavities in bone parts and cavernous bone tissues can be distinguished from hollows related to plants when they are not lined by dense bone tissues (the plant/plant hollows are not lined by dense bone tissue). Mineralised coprolites exhibit a higher X-ray attenuation than non-mineralised coprolites. Gypsum mineralisation occurred in various forms after the coprolite was produced. This is visible as tiny inclusions, large flower-like acicular crystals within large pores, or as continuous infill of cracks and interfacial voids.

6.4.3 Bone content: fish

A large number and a great variety of fish bones appear on the scans of most of the coprolites. Many bones are small and fragmented. Some are complete and relatively large (10 to 20 mm) concerning the size of the coprolites.

The type of certain fish bones is easily recognised on the scans based on the bone morphology. Teeth with their thick-walled hollow conical form, scales with their very thin plate shape, and bony fins with their long U-tube structure can be observed even on a single 2D scan image. Vertebrae with their hourglass-shape can be detected on a 2D slice where a white ellipse or thin white arches show up. 3D volume rendering was required in some cases to confirm the identification, especially when the vertebra is not complete, is heavily distorted, or is partially altered either by cutting, cooking, digestion, or taphonomic processes. A 3D visualisation can also assist the naked eye in discerning other bones with a specific shape, such as skulls with their two ocular orifices, segmented fins, jaws or palates, with or without teeth still attached. The inner structure of fish bones also helps to secure a diagnostic on the bone function. The main bone tissue, the cortex, a compact tissue that protects the cavernous inner tissue called trabecular tissue, can be distinguished on the micro-CT scans. This tissue provides rigidity with limited material.
Teeth consist of a thick cortex that shields the inner tissue made of small size trabeculae while ribs and spines appear as hollow conical tubes without such spongy tissue. Bony fin rays are

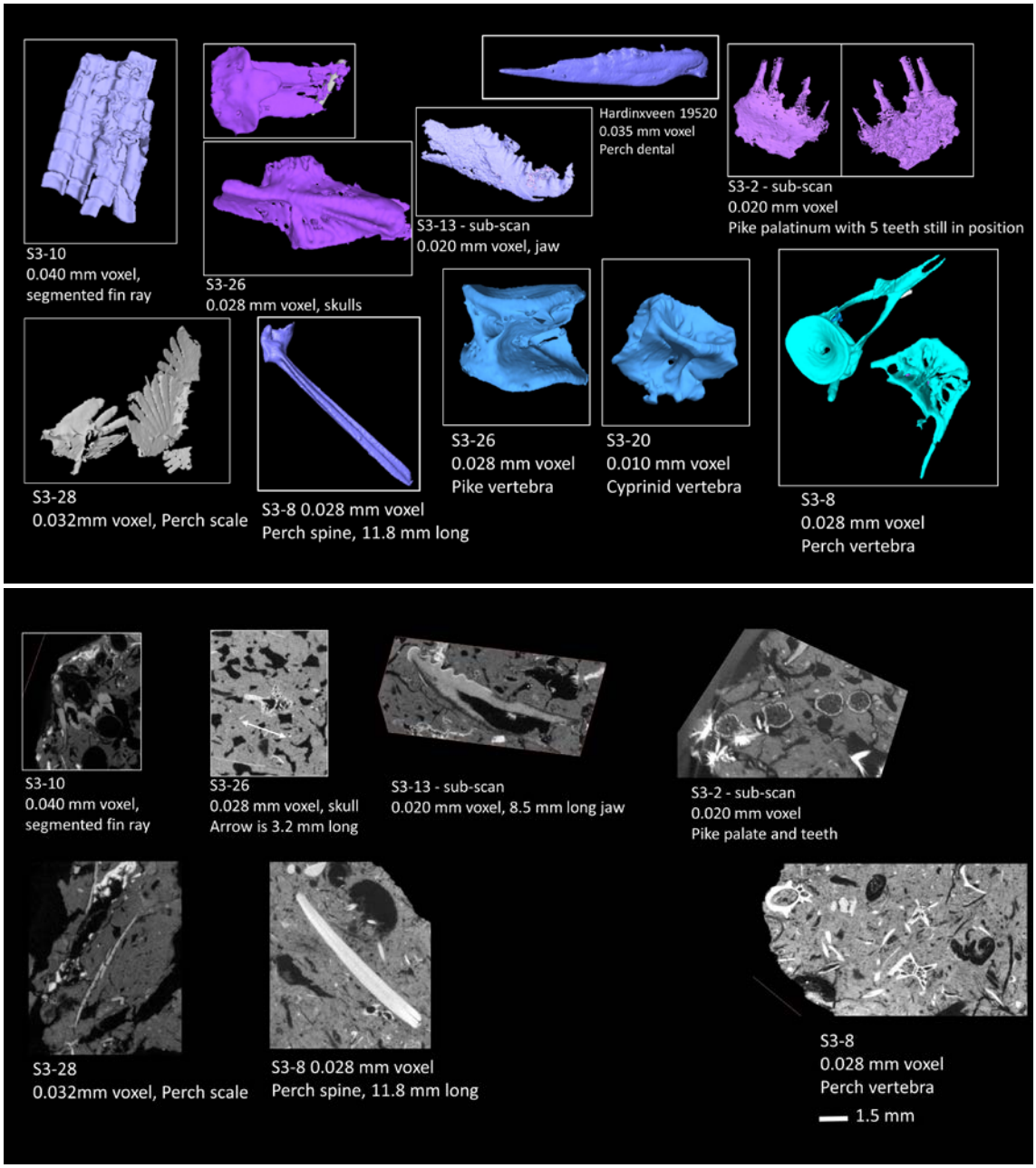


Figure 6.6 Examples of 3D a. bone surfaces; and b. anatomies extracted from the scans.

compact. Striations prolong valleys visible at the surface of some scales. Examples of 3D bone surfaces and anatomies extracted from the scans are presented in Fig. 6.6. The result of the sorting per bone type for coprolite S3-2 is presented in Fig. 6.7. The presence of many fish head bones, vertebrae, scales and fins in the coprolites is direct evidence of the absence of fish- cleaning before cooking or ingestion.

Identification of a bone at the fish species level is only possible for bones fulfilling certain characteristics. It requires a bone in a good state of preservation for 3D visualisation. Pike teeth can be distinguished from cyprinid and perch teeth and spiky bones (fin rays and ribs) by their large size and curvature (Fig. 6.3.a). The lateral external structures of vertebrae are more discriminant than the hourglass-shaped internal parts of vertebrae. They exhibit various arrangements of plate-like ridges and net-like trabeculae. Net-like structures are more prone to degradation and more difficult to extract digitally than thick plate-like structures. Intersecting the vertebra with a transverse slide cutting through the preserved lateral structure of the vertebra can help to make a diagnostic. Pike vertebrae have large thick-walled 'compartments' (concavities) with a square section between the ridges (Fig. 6.3.b). Cyprinid vertebrae have thin-walled 'compartments' with a triangular section (Fig. 6.3.c). Perch vertebrae have an extensive net-like lateral structure

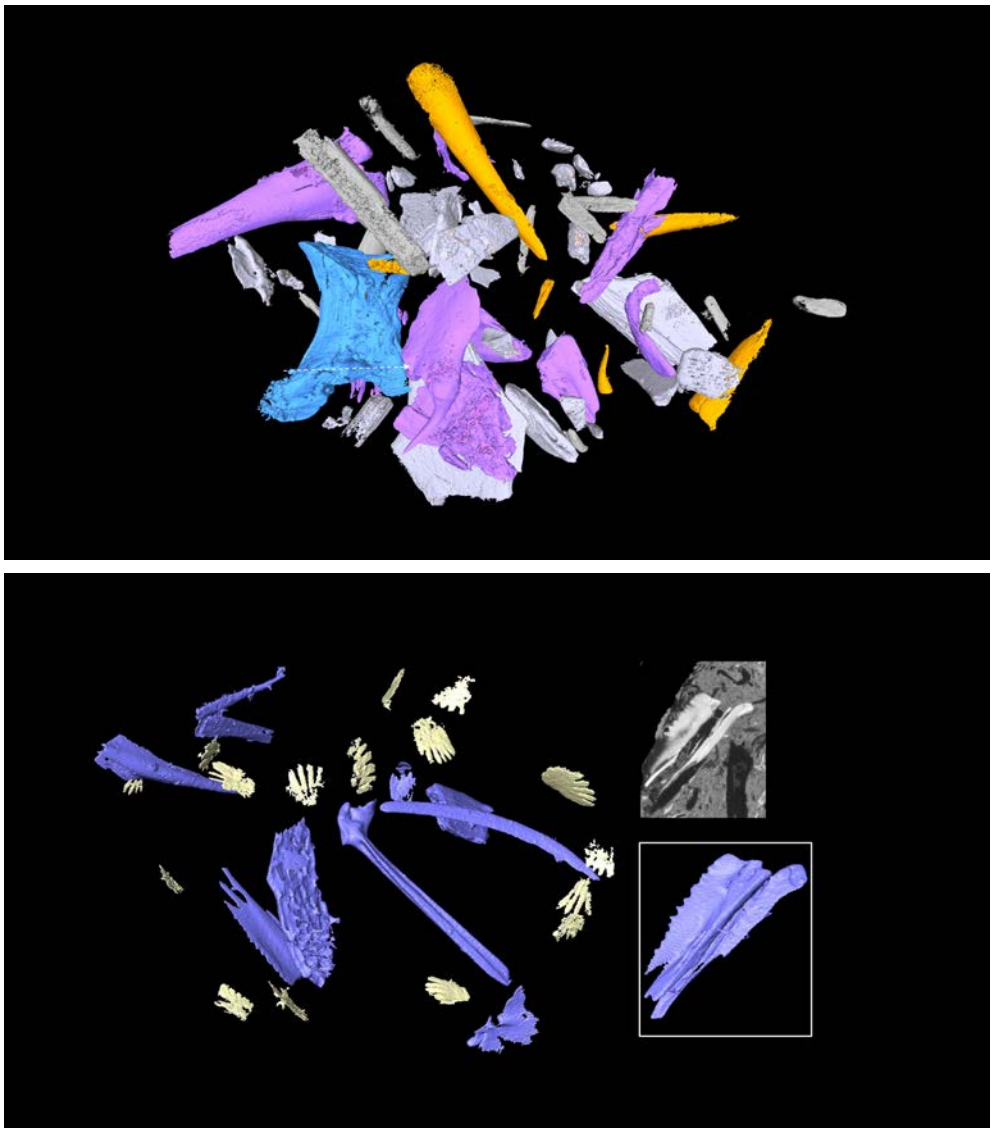


Figure 6.7 Bone sorting. a. in S3-2 using subscan with 0.020 mm voxel size. Teeth are coloured in orange, the vertebra in blue, and other bones with a specific shape in violet. Note that bone (a) is a crushed pike tooth. Among the bones coloured in white are many plate-shaped and/or elongated bones. b. in S3.8 using 0.028 mm voxel scan. Perch scales are represented in white and diverse elongated bones in violet.

Figure 6.8 Examples of 3D prints of fish bones. S3-26 pike vertebra seen from a different point of view, S3-13 jaw and S3-2 pike tooth on a display stand. Magnification x10. The pike tooth replica is 5.5 mm long.

(Fig. 6.3.d).The signature of a perch scale on a scan is unique: it looks like a waving hand (Fig. 6.6). Magnified 3D prints of bones (Fig. 6.8) were found to be practical for confirming diagnostics made on scans using physical reference collections and open-source databases[119] where photographs or 3D stereo-photogrammetric models of indicative bones are displayed for many fish species. So far, all the remains identified on the scans at the species level were found to belong to freshwater fish.

While some fish bones have a characteristic signature on the scans, the vast majority of them cannot be identified in terms of bone part or fish species on the scans nor on physical replicas. Traditional identification under the binocular microscope is also challenging. No more than six bone types (vertebra, spine, tooth, palatinum, dentale, and quadratum) could be identified and related to a fish species, either pike, cyprinid, or perch (see Chapter 7, Table 7.1).

[119] http://fishbone.nottingham.ac.uk/collections.

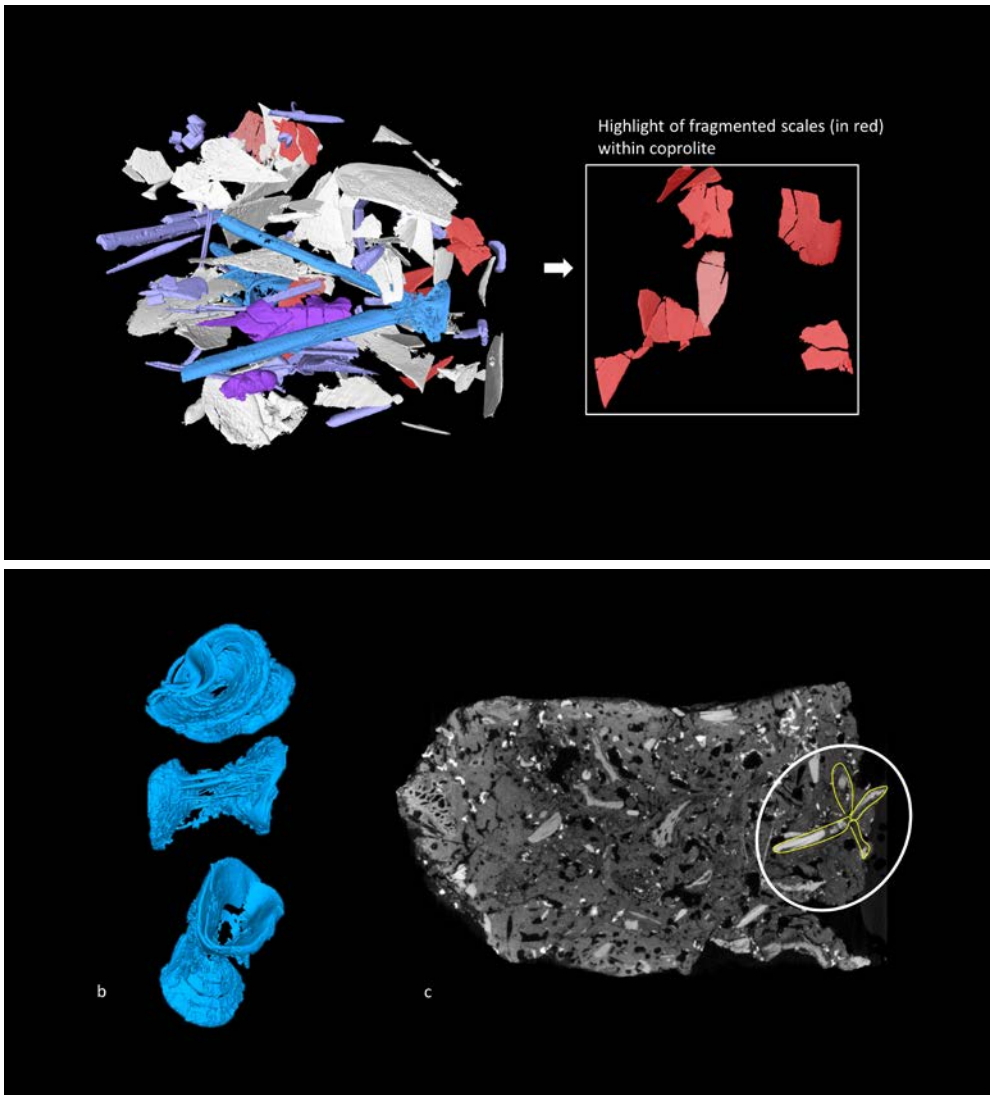


Figure 6.9 Bone deterioration. a: many fragmented scales (red) in Hardinxveld 19952 crossed by many cracks (see Fig. 6.5). The coprolite also contains connected and disconnected fin ray elements and well preserved vertebrae (blue) (0.016 mm voxel scan); b: distorted vertebra in S3-5; c: partially weathered vertebra in S3-20 (0.040 mm voxel scan).

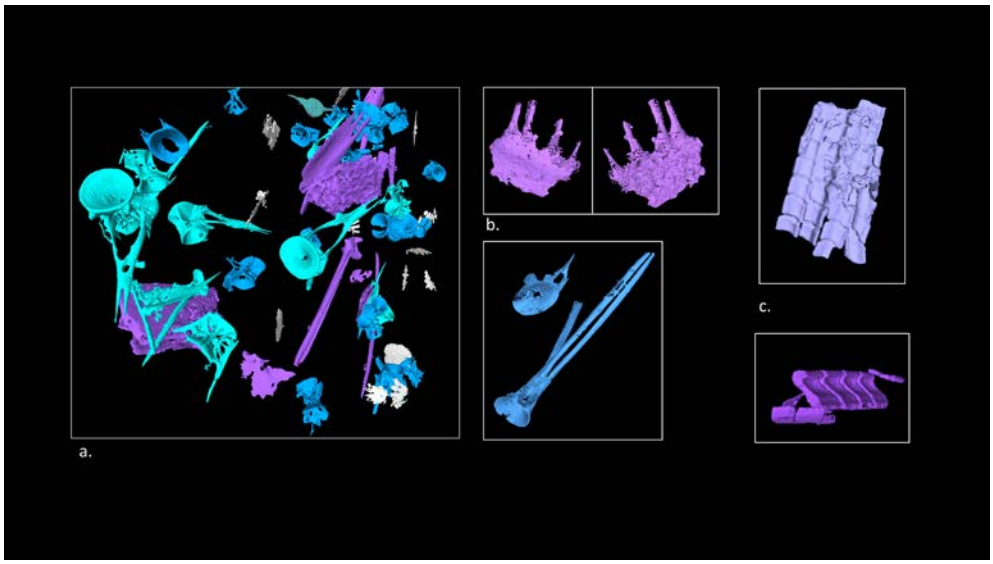


Figure 6.10 Connected bone parts. a: many 0.4 to 2.5 mm high perch vertebras, many of them still connected to one of their spines (turquoise). The longest spines are about 6 mm long. (S3-8, 0.028 mm voxel scan), b (above): 2.9 mm wide palatinum with teeth (S3-2, 0.020 mm voxel sub-scan), b (below): perch vertebras, partially connected to their spines (Hardinxveld 19952, scan 0.008 mm voxel) c (above): possible segmented finray (S3-10 - sub-scan 0.020 mm voxel), c (below): distal segmented finray (Hardinxveld 19952, 0.016 mm voxel scan).

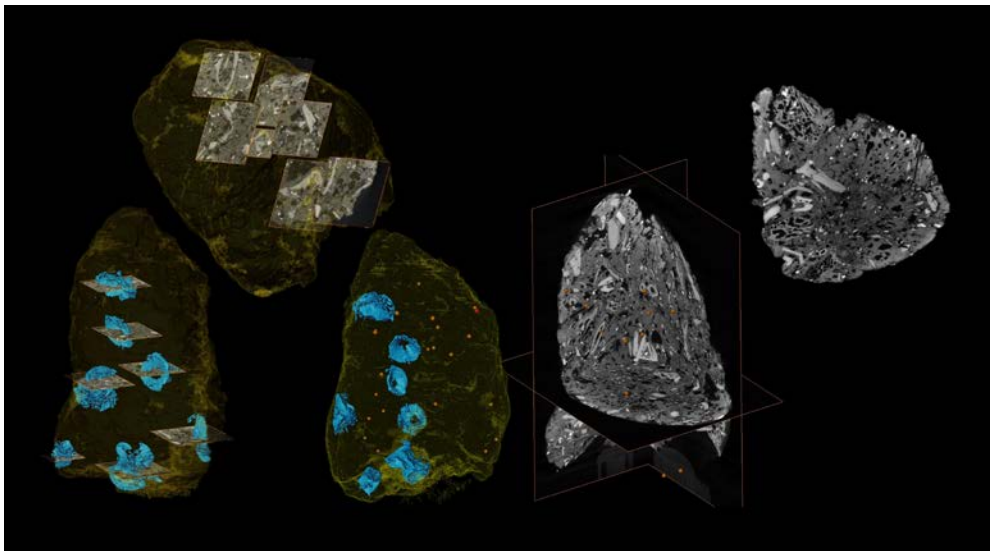


Figure 6.11 Spatial distribution of vertebra fragments and pike teeth in S3-2 (0.040 mm voxel scan). Brown dots point to teeth. Note also the large 4 to 5 mm high cavernous bones (right).

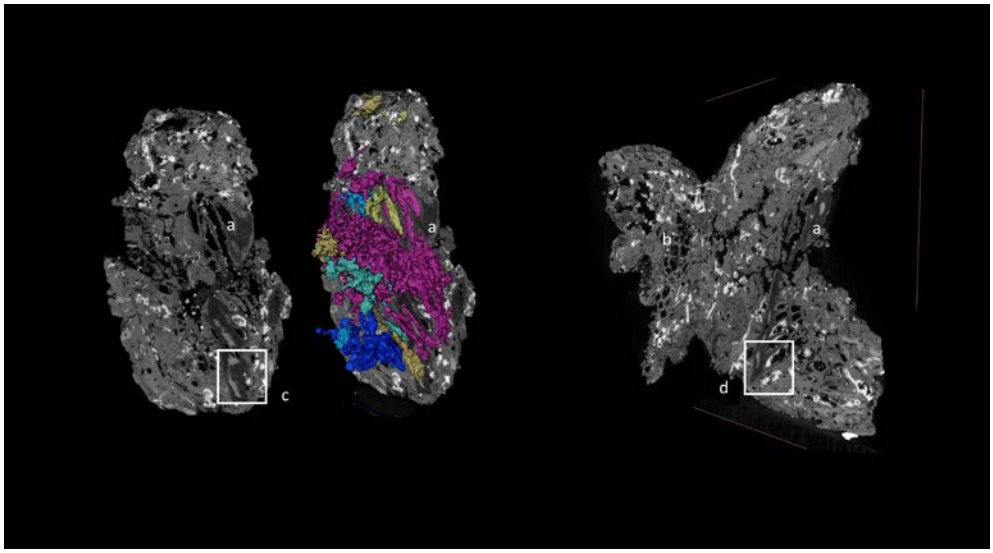


Figure 6.12 Large cavernous bones with pointed elongated cavities in S4-4 (0.025mm voxel scan). a. 17 mm long; b. 12 mm long. Note the variable X-ray attenuation values of these bone tissues (c) and their gypsum mineralisation (d).

The degree of bone distortion and fragmentation varies. Many scales in Hardinxveld 19952 are fragmented and fragments belonging to the same scale are located next to each other (Fig. 6.9.a). Fragmentation likely occurred after the production of the faeces, when the multiple cracks crossing the coprolite developed. It cannot be excluded that vertebra fragments that are now dispersed within a coprolite originate from the same vertebra. Puzzling with 3D replicas of the pieces can help in reassembling dispersed fragments. The best examples of tooth and vertebra distortion are found in S3-2 and S3-5 (Fig.6.9 b), respectively. One can only speculate that deformation occurred during eating.

Almost all of the fish bones are present in the coprolites in isolation rather than as pieces within an articulated group of bones. When two vertebrae are adjacent to each other, they are placed in an awkward position. No series of articulated vertebrae such as those identified in the scans of the Swifterbant midden deposits have been found in the coprolites.[120] Examples of articulated bones that have survived food preparation (if any), eating, digestion, soil degradation, and post-recovery degradation processes are a palate with four teeth still attached, still in position, in S3-2, and a series of connected segments belonging to a distal fin ray in S3-10 (Fig. 6.6 a) and Hardinxveld-19952 (Fig. 6.9 a). On several occasions, one or two spines are found to be fixed to a full vertebra. S3-8, the cake-like coprolite, yielded the highest number of vertebrae (more than fifty!). A dozen of them are almost complete and attached to one of their spines. An overview of connected bone parts extracted from the scans is given in Fig. 6.10. Bone remains are not spread evenly throughout the coprolites (Fig. 6.11) which renders statistics on bone parts extracted from subsamples unreliable. As the scanned coprolite pieces do

[120] Huisman *et al.* 2014.

not correspond to the coprolites sieved for bone analysis in some cases, it is normal that some bones identified during traditional sieving cannot be traced back in the micro-CT scans.

6.4.4 Bone content: other

In addition to fish bones, some mammal bones and one bird bone have been identified (Chapter 7). The numerous large trabecular bone tissues which dominate the bone fragments of S3-2, S3-20 (Fig. 6.11, right) and S4-4 (Fig. 6.12) on the scans are uncertainly attributed to mammals. A duck ulna was found in Hardinxveld-19952, but could not be traced back in the scan (see Appendix IV). Hardinxveld-19952 consisted of several fragments and the fragment subjected to bone analysis was not the fragment which was scanned. Many bones were too small or without a specific shape to be recognised at a detailed taxon level.

6.4.5 Overview of the bone content

Coprolites produced by humans and animals could not be distinguished from each other based on their bone content. Fish bones have been found in all of the coprolites. A few specific finds are worth mentioning. Fish bones observed in the scans have been related to only three species: pike, cyprinid and perch. This does not mean that catfish, bream, etc. were not on the Neolithic menu. More training would be needed to recognise these on the scans. Extending Sakashita *et al.*'s visual and textual comparative morphological examination of fish vertebrae to freshwater fish species often recovered at Neolithic sites would greatly help.[121] On some occasions, a mixture of fish was eaten (pike and cyprinid in S3-20, pike and perch in S3-26 and S3-28) while on others, only one fish type (perch in S3-8) was (apparently) consumed. Fish was sometimes eaten together with mammals (S3-2 and S3-20). It usually takes one to three days after eating for food to pass through the human body as stool. Therefore, assumptions can only be made about the composition of weekly meals based on the kind of food remains found in the individual coprolites.

Vertebrae are present in all of the coprolites except S3-4 and S4-4. Vertebra with (almost) intact spines have been extracted from Hardinxveld-19952, S3-8 and S3-26, with no less than a dozen in S3-8, the flat cake-like coprolite. Head bones (skull, palate, jaw) other than teeth have been observed in the Hardinxveld-19952, S3-2, S3-13, and S3-26 coprolites. One of the largest diversities in bone parts is observed in Hardinxveld-19952. It is clear that fish was consumed without descaling, beheading or deboning. Many fish bones (numerous plate-like bones, several teeth and a large distorted vertebra, 6.3 mm high) are also present in S3-5, the coprolite tentatively attributed to a herbivore based on lipid analysis. Fish might have been ingested while the animal was grazing next to kitchen middens. Tongue hair facing the throat prevents ruminants from spitting out any foreign bodies they ingest. There are also cases where cattle is known to eat meat, specifically, dead rabbits.[122] Coprolites whose producer could not be identified have a bone content that does not stand out.

Hundreds of bones or bone fragments are found in some coprolites. Most have a sub-millimetric or millimetric size and could have been ingested by a human being even if they had not been softened and rendered more edible by boiling or any kind of heating. In all of the coprolites, except S3-4, bones between 10 and 20 mm long have also been retrieved. Several of these are in a state of preservation that would allow a detailed morphometric analysis aiming to characterise the size of fish consumed following the procedure set by Charles *et al.* for modern fish vertebrae.[123] To be ingested by humans, these relatively large bones would have had to be softened by some kind of food preparation (cooking or maceration). In any case, bones would have contributed significantly to the dietary intake of calcium, lipids, and amino acids.

The contrast between bone, amorphous faecal matrix and plant tissues on the scans varies. Both cortex and cavernous bone tissues can present a low X-ray attenuation because of weathering processes that took place at any time after ingestion. It cannot be excluded, for example, that some bones were burnt during cooking in ash layers or roasting over open fires.[124] although one would expect to find more large pieces of wood charcoal with rectangular cross-sections within the coprolites.[125] However, there

[121] Sakashita, Sato & Kondo 2019.
[122] Wallisdevries 1996.
[123] Charles *et al.* 2017.
[124] Huisman *et al.* 2014.
[125] Ngan-Tillard *et al.* 2015.

are clear indications at S4 for the burning of reed-dominated material[126], so a lack of charcoal may also be because non-woody material was used in cooking fires.

The lack of contrast between tissues complicates digital sieving, especially when the cavernous texture of plant and bone tissues are similar. Quantifying the proportion of fish in the human diet of the Neolithic Swifterbant Culture from scans is still a challenge. It is clear that bone statistics derived from the 3D volume rendering or thresholding tuned to highlight only bright tissues would be erroneous. Moreover, because only the fish that are eaten whole turn up in the scans; of the larger fish, the bones would not be ingested and therefore not recovered in the coprolites.

6.4.6 Botanical content

One of the most striking outcomes of the micro-CT scans is the very large concentration of seed impressions that form the bulk of coprolites S3-10 (Fig. 6.13) and S3-11. Inspection of thick seed testa tissue lining the walls of some seed phantoms protruding on the surface of the coprolites using a stereo microscope allowed the identification of the seeds to white water-lily. Many fragments of seed testa were also detected using the SEM (Chapter 8). Negative impressions of crab apple seeds have also been retrieved digitally from two coprolites: one entire seed from S3-10 (Fig. 6.13 b and c) and three large fragments belonging to three different seeds from S3-28. The shape and size of apple seeds make their detection straightforward. Other isolated seed-like shaped voids have been found, for example, in S3-4, S3-8, S3-15, S3-18, S3-26 (Fig. 6.14), and S3-28. Some remains were identified with SEM (Chapter 8). On some occasions, plant tissues which have survived the cooking, digestion, and subsequent soil and drying processes are visible on the scans. For example, thin membranes partially detached from the seed walls (S3-10 (Fig 6.13 b), S3-11, S3-26 (Fig. 6.14)) can be discerned.

Many coprolites bear impressions of elongated rolled herbaceous plant tissues (S3-5, S3-8, S3-13 (Fig. 6.15) and S3-18). Some of these tissues have been 3D printed to facilitate identification. The replicas were found to match in terms of size and shape the tissues observed under the SEM at low magnification. The taxonomic determination of these plant tissue remains is discussed in Chapter 8.

A large number of elongated tissues resembling stems of grass plants of various sizes can also be seen in S3-4 (Fig.6.5 b), S3-8 (Fig. 6.5 c), and S3-5 (see Appendix VI). Again, identification in the micro-CT scan images was not possible. However, both SEM and phytoliths analyses provided some identifications of these plant tissues (Chapters 8 and 9). On some occasions, charred plant remains might be present in the coprolites (Fig. 6.16).

6.4.7 Overview of the botanical content

White water-lily seeds were probably not just an addition to the diet but an important element of the diet. Considering the large quantity found in S3-10 and S3-11, it was a dish on its own, perhaps eaten with the fish and apples since remains of these have also been found in S3-10.

No cereal grains have been detected in any of our micro-CT scans. Cooked cereals are easily digested by human beings and could only be present in the coprolites in the form of tiny fragments under the detection threshold of our micro-CT scans. Evidence of cereal in the human diet and further insights on the diversity in the plant components of the human diet in the Neolithic come from the SEM observations (see Chapter 8), phytolith (see Chapter 9), and pollen and intestinal parasites analyses (see Chapters 10 and 11).

Quantifying the volumetric fraction of botanical content from the volume of pores was not attempted. Except for the large seeds, it was difficult to distinguish in an automatic mode empty or (partially) gypsum filled-in imprints from cracks, bubbles, trabeculae in bone ti ssues and inner bone cavities (ocular orifices in cranial bones, nerve canals in vertebrae, inner tissue of teeth, etc.). As already mentioned above in the section devoted to the coprolite composition, coprolites with many macrobotanical remains can be distinguished from coprolites with a dense network of fine elongated organic remains.

[126] Huisman, Jongmans & Raemaekers 2009; Huisman & Raemaekers 2014.

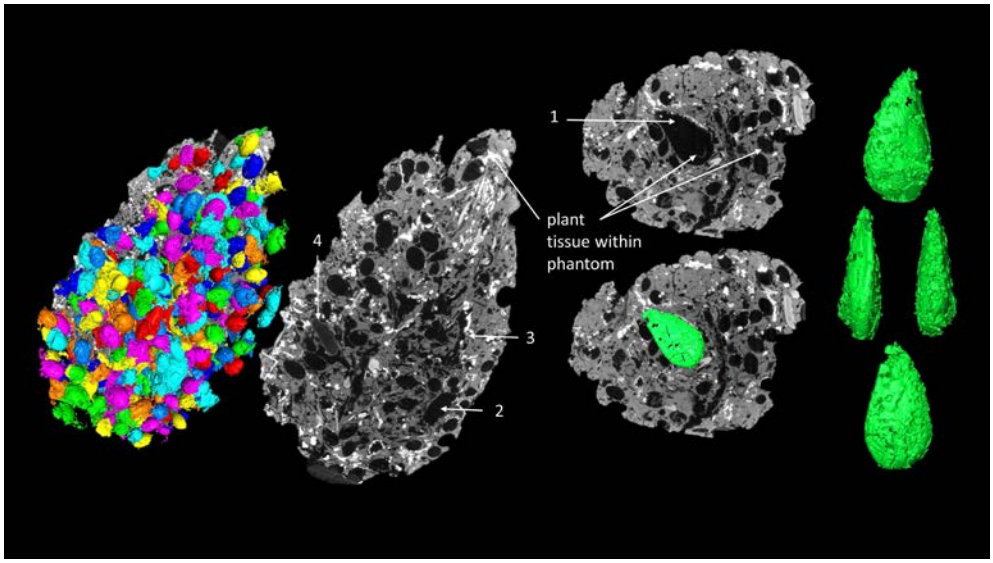


Figure 6.13 A very large concentration of 2.3 to 3.3 mm-long white water-lily seed impressions in S3-10 (scan voxel size: 0.040 mm). a. 3D impression of the bundle; b. micro-CT images revealing the phantom of an apple seed (1), a few large unidentified voids (2 and 3) and tissues (4); c. 3D representation of the 8.5 mm-long apple seed. Note the numerous thin membrane-like tissues coating or detached from the walls of plant phantoms in b.

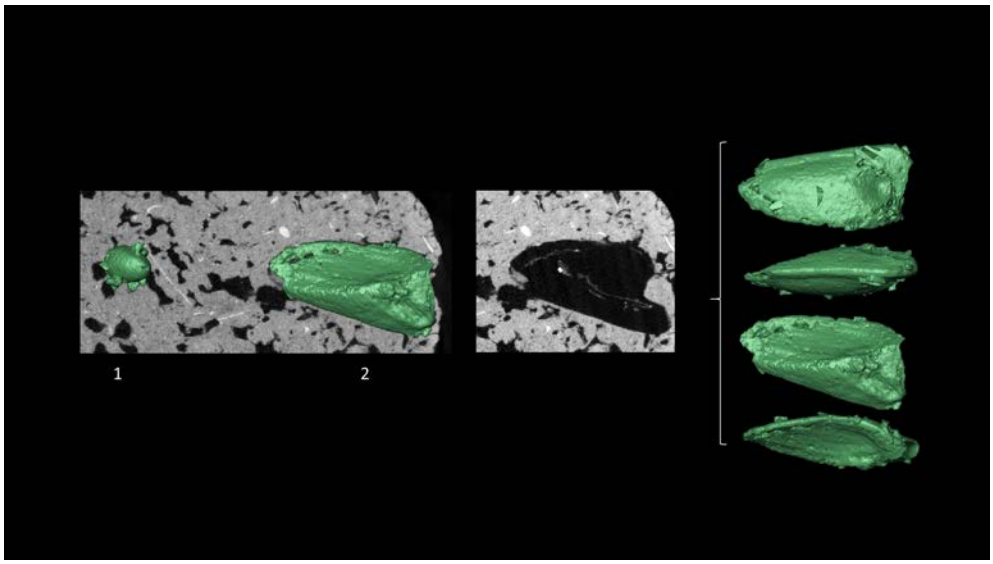


Figure 6.14 The botanical content of S3-26 (scan voxel size 0.028 mm). Among the numerous polygonal voids are a few very large voids with a distinctive shape: one 2.2 mm-long ellipsoidal void resembling the phantom of a white water-lily seed (1) and a 7 mm-long tri-facet void (2), possible fragment of apple seed/apple endocarp. (2) is probably a seed fragment that has split along a weakness inherent in the seed. Note the thin membrane.

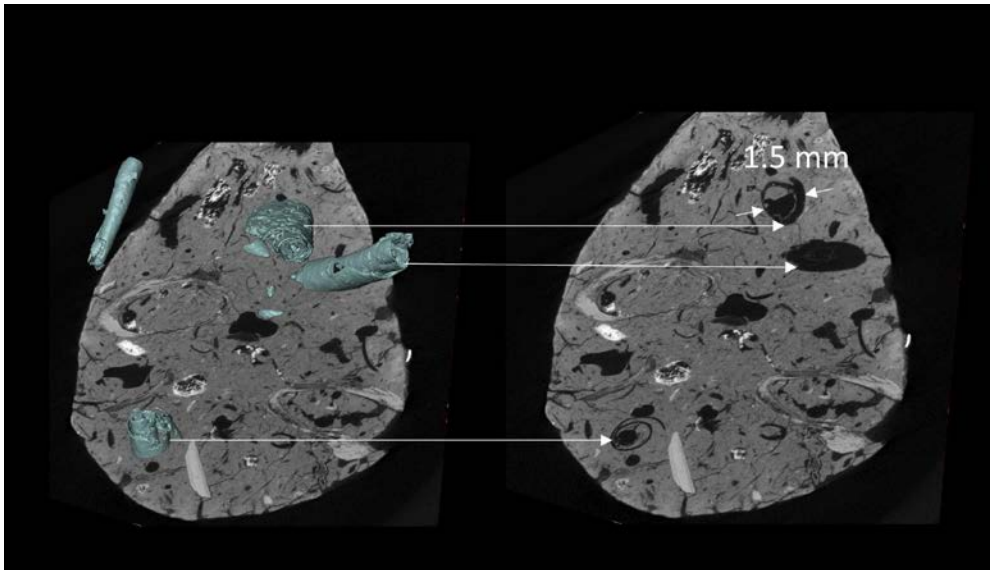


Figure 6.15 Several long rolled-up herbaceous plant tissues extracted from S3-13 and recognised and determined using the SEM. They are embedded together with large bones in a fine-grained matrix crossed by many thin tissues (subscan voxel size: 0.020 mm).

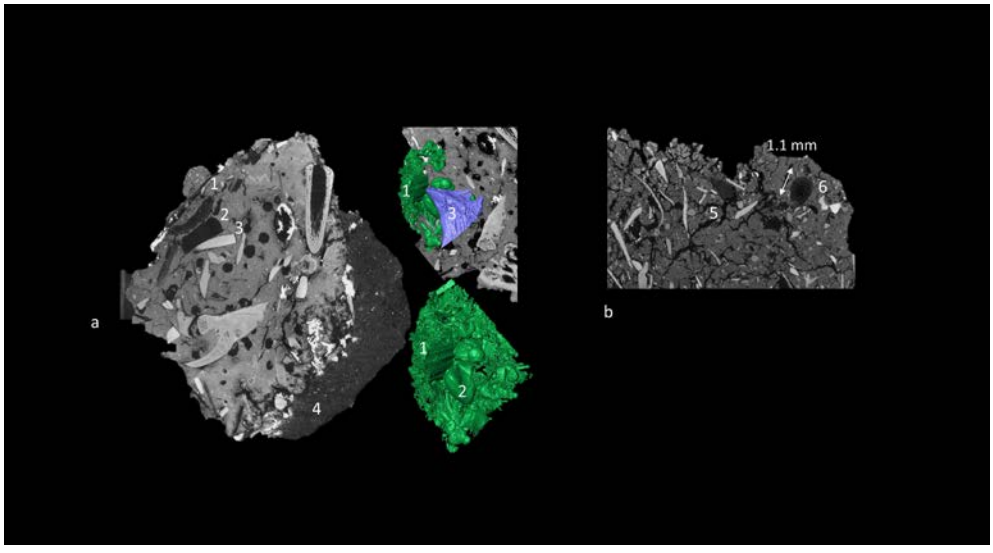


Figure 6.16 Dark features suspected to be charred plant remains. a: 1.6 mm-wide possible charred reed tissue with ribs (1) next to a large void (2) encapsulating the tip of a large bone (3). Note the ash with mineral residues (4) coating the right side of coprolite S3-2 (0.011 mm voxel subscan), b: other examples of these dark organic materials (5 and 6) in Hardinxveld 19952 (0.016 mm voxel size).

6.4.8 Groups of coprolites

The scanned coprolites can be grouped following the morphology, surface roughness, internal composition (porosity, degree of fracturing, and extent of mineralisation), and macroremain contents they exhibit on the scans. (Fig. 6.17).

The following coprolites look alike on the scans from various points of view:

- S3-2 and S3-20, with their large cavernous tissues of probably mammal origin intermixed with small and large fish bones. Note that S4-1 also contains various large cavernous tissues that might not all belong to the same taxon;
- S3-10 and S3-11, with their bundles of water-lily seeds intermingled with fish bone remains;

- S3-10 and S3-28, with a similar fish bone content combined with both apple and water-lily seeds but not in the same proportion. This shows the diverse diet of an omnivore;
- S3-13 and S3-18, with their smooth external surface, sub-rounded bubbles and rolled-up tissues. Note that S3-13 is richer in sub-rounded bubbles and S3-18 in rolled tissues and large gypsum crystals. The matrix of S3-18 also contains many thin organic tissues;
- Hardinxveld-19520 and S3-26, with their rough surfaces, a network of angular voids and large fish bones. Note the presence of several seed-like macro-voids in S3-26 only;
- S4-1 and S3-15, with their dense network of cracks and cavities filled in by gypsum mineralisation. S3-4 is also affected by gypsum mineralisation, but to a lesser extent.

The following coprolites are unique for various reasons:

- S3-4 for its bone content consisting of small bone parts only and its extensive network of thin elongated voids assumed to be organic tissues;
- Hardinxveld-19952 for its extensive network of cracks that have spread through many of the fish scales embedded in the faecal mass;
- Both S3-5 and S3-8 for their distinctive shape. S3-5 is a small cylinder without a pointed extremity and S3-8 is a flat disk. Several large elongated botanical remains are noticeable in both. The matrix of S3-18 contains many thin herbaceous tissues. S3-8 is very rich in perch vertebrae.

6.5 Discussion

Many zoological remains (teeth, scales, vertebrae, ribs, fin rays, skulls, etc.) and only a small number of plant remains (for example, a fragment of rachis internode of domesticated barley[127] or apple seeds, this volume) can be unambiguously recognised on micro-CT scans with a 0.030 mm voxel size. In some cases (water-lily seeds), a first diagnostic has to be secured by cross-checking the micro-CT signature of the remain with its identification using a stereo microscope. It is only in combination with SEM analysis that some tissues may be assigned to a species or genus. The added value of higher resolution micro-CT scans (sub-micrometre) on smaller coprolite fragments should be investigated.

[127] Cappers & Neef 2021.

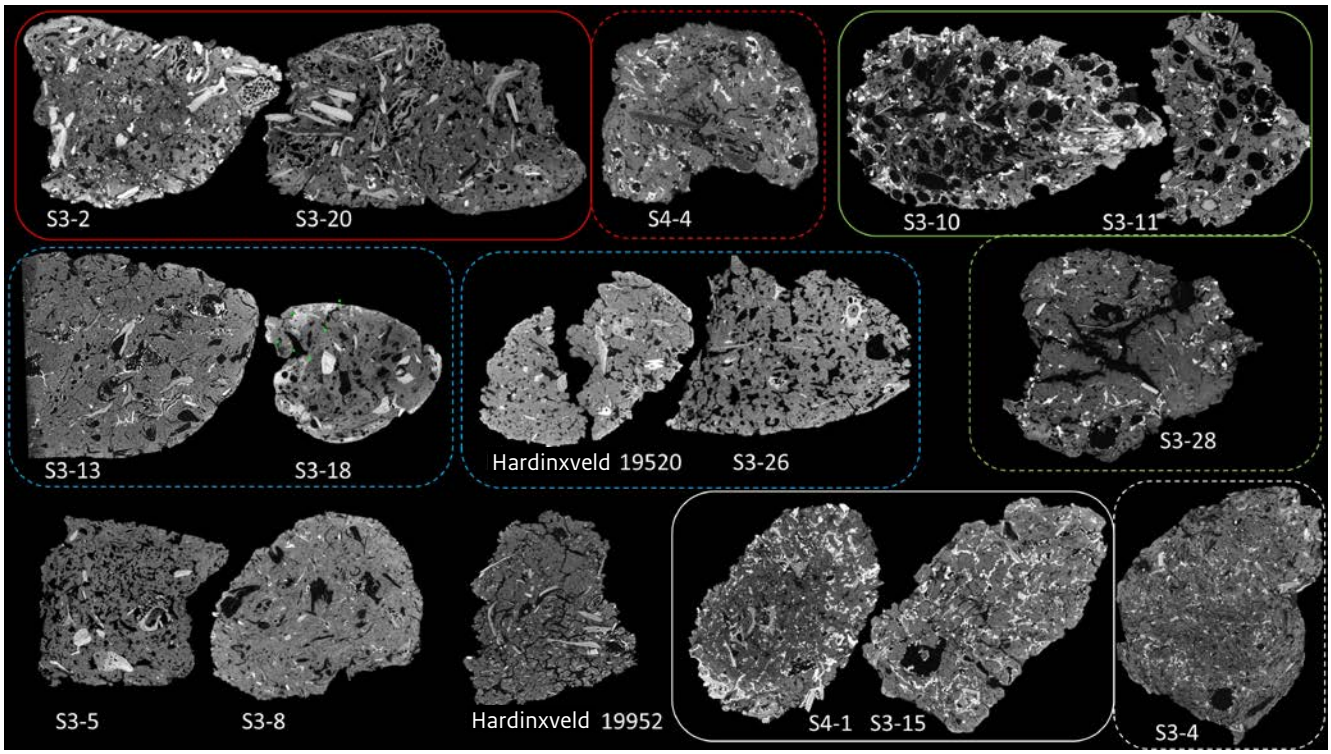


Figure 6.17 Grouping of coprolites based on micro-CT scans. Dashed lines indicate less similarity than continuous lines.

From the thorough inspection of the scans by both archaeobotanists and archaeozoologists, it will be possible to identify more organic remains present in coprolites. It is foreseen that mammal bones such as those tentatively identified in S3-2 and S3-10 will be distinguishable in scans after some training and additional chemical compound analyses. In addition to 3D morphology, the internal structure that ecofacts (plany and animal remains) exhibit on a micro-CT scan provides clues for identification. Illustrated catalogues such as created in this research (Fig. 6.3), in line with the inventory published by Sakashita *et al.*, will increase the archaeological value of micro-CT scans.[128]

Micro-CT scans unveil certain aspects of cooking and consumption habits better than other techniques used in modern coprolite studies. These techniques require some degree of physical separation which damages the coprolite, fragmenting fragile remains and other ingredients that were ingested in the same meal. Additional chemical analyses or microscopic observations on tissues that appear degraded on the micro-CT scans are needed to infer more information from the scans on the type of deterioration (partial carbonisation, leaching, etc.) that the tissues have sustained.

6.6 Conclusions

The use of micro-CT scans at a very early stage of coprolite studies is highly recommended. It can optimise the selection of coprolites for multi-disciplinary analyses, rationalise the destructive subsampling of coprolites and guide the micro-excavation of specific organic remains. The potential of micro-CT scanning is illustrated by studying a large assemblage of Swifterbant Culture coprolites in a non-destructive way. Collaboration with archaeobotanists and archaeozoologists is crucial for the recognition of organic remains on micro-CT scans and to extend the value of micro-CT scans in the study of ancient coprolites and, more generally, archaeological soils and artefacts.

The main questions of our research project concerned the dietary diversity of the Swifterbant Culture, with attention to both plant and animal components. This micro-CT investigation showed the omnipresence of fish in the Neolithic diet of the Swifterbant Culture. Small pike, cyprinids and perch were often on the menu, sometimes associated with crab apples and white water-lily seeds. It seems that some/most fish was eaten without much cleaning. No chain of vertebrae was found. The cooking, consumption or digestion processes including mastication would have separated and dispersed them.

The evidence for the consumption of plant foods in general, and of cereals in particular, was of great interest. No traces of cereals were found on scans of 0.010 to 0.040 mm voxel size. Other plant remains such as seeds may have completely disappeared and only an impression of their shape is visible in the coprolites. While the human eye is capable of distinguishing various organic remains or phantoms of those remains in the scan of a coprolite, it remains difficult and time-consuming to extract them digitally, in a (semi-)automatic mode. Even bones cause difficulties. The presence of tissues more resistant to degradation in the negative impressions left by plant remains should be targeted by micro-excavation for more detailed observations using a stereo microscope or SEM.

Concluding whether the producers of the studied coprolites were humans, dogs, pigs or other animals is not possible from the scans. The shape and roughness of the coprolites are too similar. Also, the macroremains they contain are not exclusive to humans, since it is likely that dogs and pigs would have fed on food left over by humans or even on human coprolites when they were available. It is difficult to discern differences in the degree of mastication as the observed bones and plant remains are relatively small. Even the large bones could have been ingested by a human if softened by cooking.

[128] Sakashita, Sato & Kondo 2019.

7 Animal bone

J.T. Zeiler

7.1 Introduction

Our knowledge of the human consumption of animal products is mainly based on archaeozoological analysis of slaughtering and consumption waste: the remains of mammals, birds, fish, and molluscs. However, sometimes it is not clear if a certain species was consumed or ended up accidentally in the bone assemblage as part of the background fauna. This is not the case with bone remains from human coprolites: they give direct information on what was eaten.

7.2 Material and methods

Before the archaeozoological analysis, a selection of coprolites from Hardinxveld-Giessendam De Bruin (Late Mesolithic – Early Neolithic) and Swifterbant-S3 and -S4 (Early Neolithic) were subjected to micro-CT scans (Chapter 6). These scans made clear that the coprolites contained animal remains, such as fish vertebrae (Fig. 7.1). Subsequently, after sampling the coprolites for SEM and microfossil analyses, the zoological material was separated from the coprolite matrices.

In total, animal remains from 13 coprolites were analysed, two from Hardinxveld-Giessendam De Bruin (Hardinxveld-19520 and Hardinxveld-19952) and eleven from Swifterbant-S3 and -S4 (S3-2, S3-4, S3-5, S3-8, S3-10, S3-15, S3-18, S3-20, S3-26, S3-28 and S4-1) (Table 7.1). The identifications of the remains were conducted with the aid of the author's reference collection of bone material. The remains that could be identified to species/genus/family level were quantified, while the numbers of the non-identifiable remains were estimated and divided into three categories: 1-9, 10-49, and 50-99 non-taxonomically identifiable fragments.

7.3 Results

7.3.1 Hardinxveld-Giessendam De Bruin

The zoological contents of the two coprolites from Hardinxveld-Giessendam De Bruin consisted mainly of fish remains. All of the identified remains came from perch (*Perca fluviatilis*), all but four (two caudal vertebrae, one dentale and one fin ray spine) were scales. The unidentifiable material may include more perch

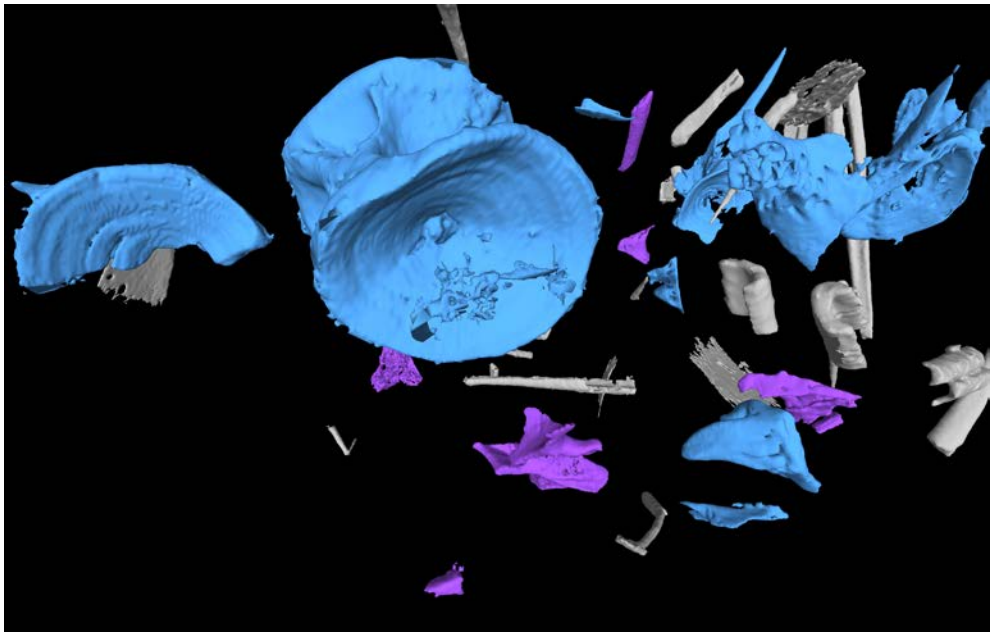


Figure 7.1 Contents of the Swifterbant S3-15 coprolite with fish vertebra (in blue); vpc = precaudal vertebra; vca = caudal vertebra. Photo: Dominique Ngan-Tillard.

scales, but they are too fragmented for reliable identification. An earlier analysis of the fish remains from Hardinxveld-Giessendam De Bruin showed that pike and perch were among the most numerous species represented. However, while the fish remains in the coprolites came from very small individuals of about the same sizes as in the Swifterbant material, the pike bones that were studied by Beerenhout all derived from much larger individuals of at least 40 cm long.[129]

In both samples, some mammal bone fragments were found. In addition, one bird bone could be identified: a distal fragment of an ulna of a duck (Anatidae).

7.3.2 Swifterbant-S3 and -S4

The vast majority of the zoological remains in the studied coprolites came from fish. Only in one coprolite (S3-20), several mammal bone fragments were present. As far as the fish remains could be identified, pike (*Esox lucius*) was the most abundant species, occurring in nine of the eleven coprolites. Perch and the carp family (Cyprinidae) were present in a few coprolites. In all cases, the sizes of the remains pointed to very small individuals of an estimated length of no more than ten cm.

Among the pike remains, vertebrae (mainly precaudal) were the most abundant. In addition, parts from the head (mainly teeth; Fig. 7.2) and fin ray spines were present. As for the cyprinids, three caudal vertebrae and two fin ray spines could be identified, while the perch was represented by three precaudal vertebrae, one (right) articulare, and 14 scales. Perch scales have a very specific, 'hand-like' shape (Chapter 6, Fig. 6.6a) and are therefore easy to identify.

In an overview of the fish remains from Swifterbant-S3, both pike and perch are mentioned, as well as four cyprinid species: bream (*Abramis brama*), rudd (*Scardinius erythrothalmus*), roach (*Rutilus rutilus*) and tench (*Tinca tinca*).[130] However, their remains were not identified in the coprolites.

Three coprolites from Swifterbant-S3 (S3-2, S3-8 and S3-20) contained charred bone fragments. The material was too damaged and fragmented to make any identification possible.

[129] Beerenhout 2001.
[130] Brinkhuizen 1979.

Table 7.1 Animal bone from Hardinxveld -Giessendam De Bruin and Swifterbant -S3 and -S4 .

	pike					cyprinid		perch							
	vertebra	tooth	palatinum	quadratum	spine (finray)	vertebra	spine (finray)	vertebra	articulare	dentale	spine (finray)	scale	fish, indet.	duck	mammal, indet.
Hardinxveld 19520	-	-	-	-	-	-	-	-	-	1	-	1	+++	-	+
Hardinxveld 19520	-	-	-	-	-	-	-	-	-	1	-	1	+++	-	+
S3-2	7 (vpc)	6	1	-	-	-	-	-	-	-	-	-	++	-	-
S3-4	-	-	-	-	-	-	-	-	-	-	-	-	+	-	-
S3-5	1 (vca)	1	-	-	1	-	-	-	-	-	-	-	++	-	-
S3-8	-	-	-	-	-	-	-	3 (vca)	1	-	-	5	++	-	-
S3-10	2 (vpc)	-	-	-	-	1 (vca)	2	-	-	-	-	-	++	-	-
S3-15	2 (vpc)	-	-	-	5	-	-	-	-	-	-	-	++	-	-
S3-18	1 (vpc)	16	-	-	-	-	-	-	-	-	-	-	++	-	-
S3-20	1 (vpc)	4	-	1	2	2 (vca)	-	-	-	-	-	-	++	-	++
S3-26	1 (vpc)	-	-	-	-	-	-	1 (vpc)	-	-	-	6	++	-	-
S3-28	2 (vpc)	1	-	-	-	-	-	-	-	-	-	3	+	-	-
S4-1	6 (vpc)	-	-	-	-	-	-	-	-	-	-	-	++	-	-

+ = 1-9 fragments; ++ = 10-49 fragments; +++ = 50-99 fragments. vpc = precaudal vertebra; vca = caudal vertebra.

Figure 7.2 Pike tooth embedded in coprolite S3-18. Photo by Dominique Ngan-Tillard.

In only one case (S3-8) it can be said that we are probably dealing with a fish bone fragment.

7.4 Discussion

The majority of the zoological remains that were found in the coprolites from Hardinxveld-Giessendam De Bruin and Swifterbant consisted of fish. As far as these could be identified, perch occurred in Hardinxveld-Giessendam De Bruin as well as in Swifterbant, while at the latter site pike and cyprinids were also represented. In all cases, the remains came from very small individuals of no more than 10 cm long.

Apart from the fish, three coprolites (one from Swifterbant and two from Hardinxveld-Giessendam De Bruin) contained a small amount of mammal bone, while in one of the coprolites from De Bruin a wing bone fragment of a duck was found.

Among the fish remains, vertebrae and scales are the most abundant. This may be partly due to a difference in recognisability of, for instance, cranial elements among the heavily fragmented remains. However, it is important to bear in mind that only a very small portion of what was consumed is present in the coprolite samples. Experiments carried out by Jones on mammal and human faeces showed that less than 10 percent of the ingested bones survived passage through the digestive system.[131] Especially if medium-sized fish were eaten (24-35 cm long), survival of bone material would be poor. This is confirmed by Nicholson, who estimates an even greater loss in ingested fish of around 40 cm long, with c. 3 percent survival.[132]

Both the very small sizes of the fish and the fact that the remains include vertebrae and head bones, as well as spines and scales, indicate that the fish were consumed in their entirety, probably in a soup or some kind of stew. The SEM analysis of charred residues with fish scales encrusted on pottery sherds from the Late Neolithic site of Mienakker suggested Neolithic people prepared such meals.[133] One could imagine that the Late Mesolithic-Early Neolithic inhabitants of Hardinxveld-Giessendam De Bruin and the Early Neolithic inhabitants of Swifterbant prepared the fish in a similar way. It seems that the main ingredients were pike in Swifterbant and perch in De Bruin. The bone remains embedded in coprolite matrices suggest that sometimes mammal and bird meat was also consumed.

Pike, perch and cyprinids are without any doubt of local origin, as they appear in freshwater like the creeks/rivers and ponds around the settlements. They could have been caught in different ways, using nets and fish traps, and, in the case of large specimens, fishing rods and spears. To catch them the inhabitants did not necessarily have to get their canoes out.

[131] Jones 1986.
[132] Nicholson 1993.
[133] Oudemans & Kubiak-Martens 2013.

8 SEM analysis

L. Kubiak-Martens

8.1 Introduction

In addition to the biomolecular and CT-scan, macrofossil and microfossil analyses, the scanning electron microscope (SEM) was also applied to the Swifterbant coprolites. SEM analysis has proven to be a powerful method in coprolite studies. It was recently successfully applied to large assemblages of human coprolites from the arid regions of western North America.[133] In that study, the results of the SEM analysis provided an excellent way to depict diverse dietary components in single images, revealing the complexity of the past human diet.

SEM analysis was applied in this project as an advanced technique to identify tiny fragments of plant tissues that occasionally survived the process of food preparation and digestion and which are now embedded in coprolite matrices. Under the SEM, even small fragments of vegetative tissues can be observed and identified: leaf or stem epidermis with trichomes (or their scars), stomata or elements of vascular tissue and calcium oxalate crystals which are produced by the vegetative parts of some plants. The SEM also proved to be a powerful tool for identifying tiny fragments of cereal chaff and grain tissues embedded in processed plant food remains. This method is being successfully applied in studies of prehistoric foodstuffs, ranging from porridge-like residues encrusted on ceramics to bread-like objects and isolated lumps of processed plant materials.[134] The SEM allows a more specific taxonomic identification of the small fragments of various cereal tissues, based on their anatomical characteristics. Using the SEM, for example, emmer (*Triticum dicoccum*) and barley (*Hordeum vulgare*) chaff epidermis can be differentiated and identified, as can the grain pericarp and aleurone tissue. Therefore, the SEM offers an unmistakable identification of archaeological food remains and helps to differentiate between different cereals used for food preparation. The SEM can also assist in the identification of other fragmented plant macroremains (seeds, for example) and animal tissues, such as small bone fragments and fish scales, so we can better understand the nature of prehistoric food preparation.

8.2 Methods

In this study, 16 coprolites that were pre-examined by a micro-CT scanner (Chapter 6) were also examined using the SEM to study their internal microstructure.

Based on the results of the initial GC-MS faecal lipid biomarker assessment, this selection included six coprolites of human (S3-2, S3-4, S3-10, S3-20, S3-28 and S4-1) and two of likely-human origin (S3-15 and S4-4); three coprolites of animal origin, including 2 pigs (Hardinxveld-19952 and S3-18) and 1 ruminant (S3-5), and two coprolites of unknown source organism (S3-11 and S3-13). Triggered by their morphology, three coprolites were added to the coprolite selection for SEM analysis, even though their faecal origin was not specified in the GC-MS assessment (Hardinxveld-19520, S3-8 and S3-26) (see Table 4.1).

A portion of each coprolite was gently broken open and small fragments of coprolite matrices were mounted directly onto labelled SEM stubs using conductive carbon cement. All of the coprolites were mineralised or partially mineralised. In most cases, the matrices were solid and hard, while in others very fragile and easily crumbled into pieces. For SEM preparation, (usually) eight fragments exposing the internal microstructure of the coprolite matrix were placed on three to four individual SEM stubs, each 12 mm in diameter. This part of the sampling procedure took place with the use of a Leica stereo microscope at 6 to 60x magnification. The samples were further sputter-coated with a thin layer (c. 20 nm thick) of platina-palladium or gold, according to the procedure at each SEM laboratory. The samples were examined in two SEM laboratories: at the Naturalis Biodiversity Center in Leiden, using a JEOL JSM-6480L scanning electron microscope, and at the Cultural Heritage Agency of the Netherlands in Amsterdam, using a JEOL-JSM-IT700HR scanning electron microscope. The images were taken at different magnifications (30x to 750x).

For reference material, dried leaf and stem specimens from nearly fifty herbaceous species were obtained from the National Herbarium of the Netherlands at the Naturalis Biodiversity Center in Leiden. In addition, fresh leaves from

[133] Reinhard *et al.* 2019.
[134] E.g. Raemaekers, Kubiak-Martens & Oudemans 2013; Kubiak-Martens *et al.* 2015a; Heiss *et al.* 2017.

selected species were also collected and used as reference material in this study (see Appendix VII). The selection of plants for this reference list was inspired by the plant macroremains records from the Swifterbant-S3 and -S4 sites.[135] In addition, several species mentioned by Hillman in his work on potential green vegetables in prehistoric Europe were also added to our reference list.[136] All of the dried leaf specimens were examined under the Leica stereo microscope at 6 to 100x magnification. Selected species were examined with the use of the SEM. During this procedure, much attention was paid to the pattern of epidermal tissue. A standard high-power transmitted light microscope with a maximum magnification of 400x was used to study the anatomy of the epidermal tissue of the fresh leaves. The reference collection at BIAX *Consult*, regarding anatomy slides of chaff epidermal tissues from selected species of wheat, including emmer (*Triticum dicoccum*), einkorn (*Triticum monococcum*) and barley (*Hordeum vulgare*) were used in this study.

No attempt to dissolve the coprolites was made. However, the sieve residues from the processing of the pollen samples were examined with the use of a Leica stereo microscope and the particles of plant tissues were studied with a compound microscope.

The results of the SEM analysis are presented in Table 8.1 at the end of this chapter.

8.3 Results

8.3.1 Hardinxveld-Giessendam De Bruin

Reed (*Phragmites*) stems and other herbaceous stem tissues

Two coprolites from Hardinxveld-Giessendam De Bruin, 19952 and 19520, were studied using the SEM. In both coprolites, fragments of herbaceous plant tissues were observed. However, only in 19952 was it possible to identify some of the fragments as reed (*Phragmites*) stems (Fig. 8.1). In 19952, SEM images revealed the presence of (somewhat irregularly) undulating long epidermal cells and occasional trichomes characteristic of *Phragmites* stem and leaf epidermis. In some fragments, parenchymatous tissue attached to the epidermal surface was also observed (Fig. 8.1 a), suggesting stem (often referred to as culm) rather than leaf tissue. The epidermal cells were accompanied by gramineous-type stomata (Fig. 8.1 b).

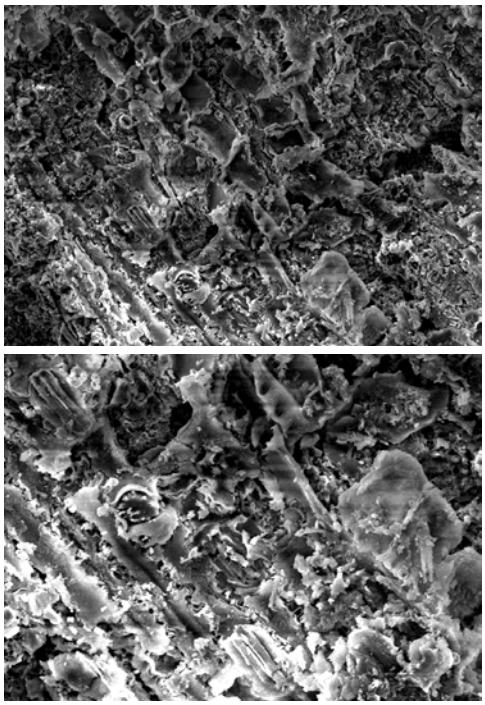


Figure 8.1 SEM images from Hardinxveld-Giessendam De Bruin, 19952. a. Fragment of reed (*Phragmites*) stem particle, showing parenchymatous tissue attached to the epidermal surface; b. Detail, showing epidermal cells accompanied by gramineous-type stomata.

8.3.2 Swifterbant-S3 and -S4 sites

Cereal chaff

The SEM analysis revealed cereal components in five coprolites (S3-2, S3-4, S3-5, S3-28 and S4-1). The cereal tissues embedded in the matrices of these coprolites were assigned to the epidermal tissue of emmer chaff. The epidermal remains were represented by fragments, between 400 and 800 µm, which most likely derived from light emmer chaff (often referred to as the husk), including lemmas, paleae and/or glumes. The epidermal particles comprised long and short cells, the long cells usually having walls with a regular wave pattern (for example in S3-2, S3-4 and S4-1) (Figs. 8.2 and 8.3). In two coprolites (S3-4 and S4-1), the long cells could be

[135] Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
[136] Mears & Hillman 2007.

measured. They were 80 to 100 µm in length and 8 to 12 µm wide (Fig. 8.2 a). The cell type with long cell walls with a regular wave pattern tends to occur in the lemmas and the glumes of emmer. In the paleae, on the contrary, the cell walls have a characteristic deep and irregular wave pattern. In the glumes, the epidermal cells are accompanied by stomata, which are absent in the lemma and the palea epidermis. In the lemmas and paleae, the epidermal cells are accompanied by numerous trichomes and papillae.[137] In the archaeological material presented here, epidermal cells of emmer chaff were often accompanied by trichomes (hair) (S4-1, Fig. 8.2 b) or papillae/trichome scars (for example in S3-2, Fig. 8.3 a). In a few specimens, stomata were also preserved (Fig. 8.3 b). The measurements of the cells, the frequent presence of trichomes and/papillae and, usually, the lack of stomata suggest that the particles embedded in the Swifterbant coprolites would have mainly derived either from lemmas or paleae (or possibly both) of the light chaff of emmer.

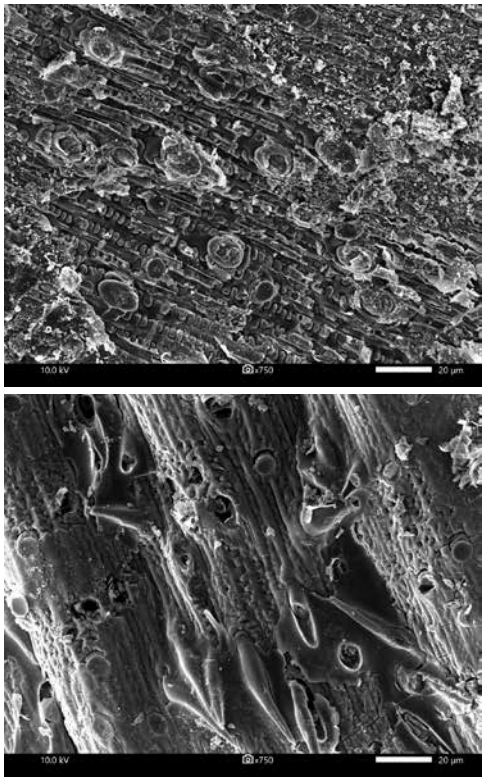


Figure 8.2 SEM images from S4-1 internal content. a. Silicified epidermal tissue of emmer chaff, showing epidermal cells accompanied by papillae and papillae/trichome scars; b. Silicified epidermal tissue of emmer chaff, showing epidermal cells accompanied by trichomes and papillae/trichome scars. Both fragments are likely from emmer lemmas or paleae.

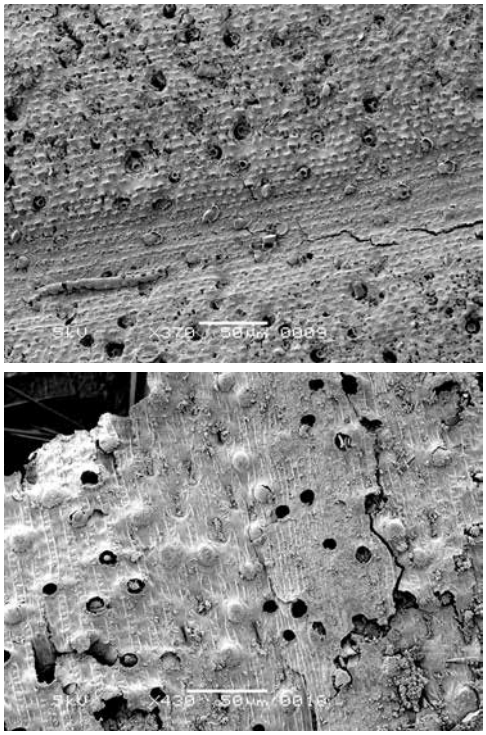


Figure 8.3 SEM images from S3-2 internal content. a. Silicified epidermal tissue, likely of emmer chaff, showing long epidermal cells accompanied by numerous papillae/trichome scars; b. Epidermal surface, likely from emmer glume, showing numerous papillae accompanied by gramineous-type stomata. Some papillae have deteriorated, leaving cavities.

Reed *(Phragmites)* stems

Fragments of leaf and stem epidermal tissue from reed were embedded in five coprolites (S3-2, S3-4, S3-5, S3-15 and S4-1). The fragments were often relatively large, sometimes 5 to 8 mm (Fig. 8.4 a). They were clearly embedded in coprolite matrices, and hence can be interpreted as belonging to the matrices and not as contamination from the soil. In some specimens (likely from the stem), the long wavy epidermal cells were accompanied by numerous papillae/trichome scars (Fig. 8.4 b). The leaf epidermal fragments were characterised by the presence of numerous gramineous stomata, sometimes referred to as 'hamburger' stomata (Fig. 8.5).[138]

[137] Based on the author's study of material obtained from BIAX reference collection.

[138] Ramsey *et al.* 2016.

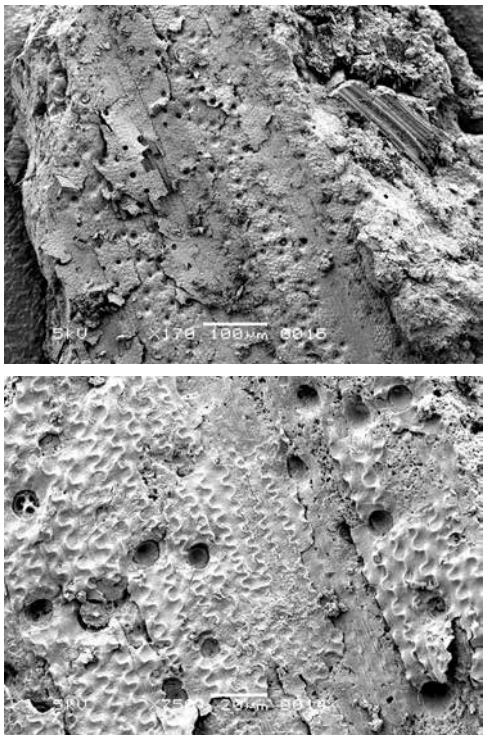


Figure 8.4 SEM images from S3-15 internal content. a. Silicified epidermal tissue of reed (*Phragmites*) stem embedded in the coprolite matrix (overview); b. Detail, showing (irregularly) wavy or undulated epidermal cells accompanied by papillae/trichome scars.

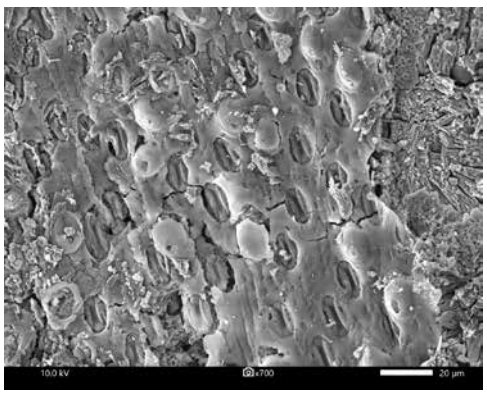


Figure 8.5 SEM image from S4-1 internal content, showing silicified leaf epidermis of reed (*Phragmites*) accompanied by numerous gramineous type stomata.

Leaves of mistletoe *(Viscum album)*

In two coprolites (S3-8 and S4-4), numerous leaf fragments of mistletoe (*Viscum album*) were embedded in the coprolite matrices (Fig. 8.6). In both coprolites, the epidermal cells of the leaf surface were smooth-walled to only slightly undulated. They were accompanied by numerous stomata. The stomata showed architecture in which the guard cells were surrounded by large subsidiary cells, which were not much different in size and shape from the normal epidermal cells (Fig. 8.6 a). In one of the archaeological fragments embedded in the S4-4 coprolite, the epidermal surface was partially eroded/altered, possibly by digestion. As a consequence, a layer of irregularly shaped parenchyma cells of the mesophyll tissue was exposed, suggesting that this fragment represents a lower leaf surface (Fig. 8.6 b).

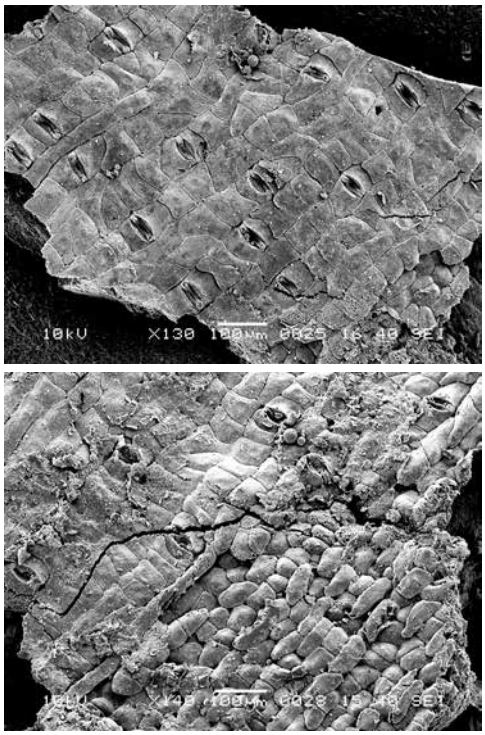


Figure 8.6 SEM images showing leaf remains of mistletoe (*Viscum album*) embedded in the S4-4 coprolite matrix. a. Epidermal cells with stomata (130x); b. Lower leaf surface showing an exposed area of irregular mesophyll parenchyma cells under a (partially preserved) epidermal layer (140x).

Archaeological epidermal tissues preserved in both S3-8 and S4-4 coprolites matched well with a reference material of mistletoe (*Viscum album*) leaf epidermis, both in regard to the cell anatomical appearance and the type of stomata (Fig. 8.7).

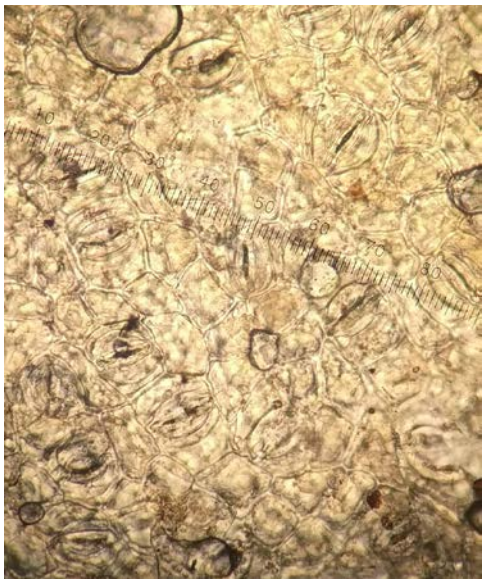
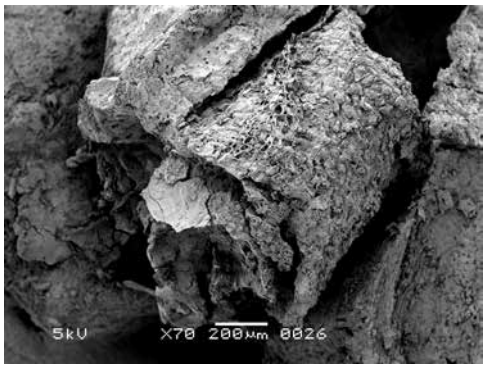


Figure 8.7 Epidermal surface of mistletoe (*Viscum album*) leaf, showing epidermal cells and multiple stomata. (scale bar: 10 stripes = 24.5 µm).



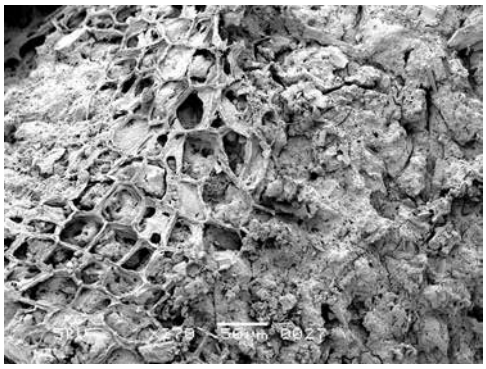


Figure 8.8 SEM images showing a leaf fragment of (likely) knotgrass (*Polygonum aviculare*) embedded in the S3-13 coprolite. a. Overall view showing rolled leaf fragment with exposed epidermal cells (70x); b. Detailed view showing epidermal tissue with cells eroded/ altered, possibly through digestion (270x). The same rolled material was observed in the micro CT-scans (see Chapter 6).

Herbaceous leaves, likely of knotweed *(Polygonum aviculare)*

Five of the studied coprolites (S3-4, S3-5, S3-13, S3-18 and S3-20) share the presence of (likely) knotgrass (*Polygonum aviculare*) leaves. This taxonomic interpretation was based on morphological and anatomical features observed using the SEM. In two of the coprolites (S3-13 and S3-20), the leaf remains were preserved as rolled-up or scroll-like fragments embedded in coprolite matrices (most clearly observed in S3-13, Fig. 8.8 a). This preservation suggests that they are derived from small leaves rather than fragmented large leaves. In the identification process, nearly fifty species of herbarium specimens (and some fresh leaves) from various families were examined (see Appendix VII). Characteristic of the appearance of the epidermal tissue, in all four coprolites, was the pattern of large somewhat square-shaped thick-walled cells of the leaf epidermis, c. 30 (to 40) x 40 (45) µm in size (Fig. 8.8 b). These epidermal cells matched well with the pattern of enlarged epidermal cells observed on the lower surface of knotgrass leaves and thus formed a link with the archaeological remains (Fig. 8.9).

Significant to mention is the fact that the fresh leaves of *Polygonum aviculare*, particularly the leaves from the top of the plant, have curled edges, which also mirrors the preservation of archaeological remains in the form of rolled tissue.

Figure 8.9 Lower epidermis of knotgrass (*Polygonum aviculare*) leaf, showing large thick-walled epidermal cells. (scale bar: 10 stripes = 24.5 µm).

Vegetative plant tissue with no further determination

In addition to mistletoe and knotgrass leaves, and reed stems/leaves there were other vegetative tissues (likely leaf fragments) embedded in various coprolites. The good examples are coprolites S3-2 and S4-4,

which contained multiple fragments of vegetative tissue (see Figs 8.10 and 8.11). Unfortunately, these remains could not be determined to the taxonomic level, but it was clear in both coprolites that the leaf tissues derived from herbaceous, likely dicotyledonous plants.

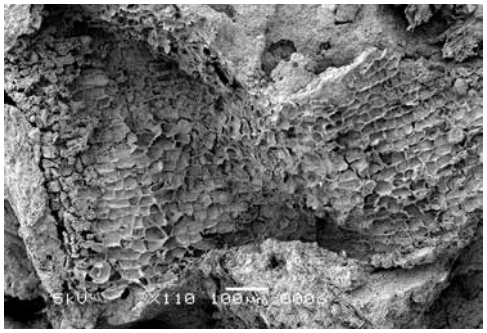


Figure 8.10 Herbaceous remains, likely leaf/stem parenchyma embedded in the matrix of coprolite S3-2 (no further identification).

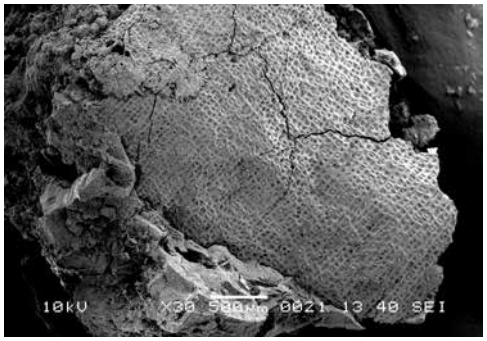


Figure 8.11 Leaf remains of a herbaceous plant species embedded in the matrix of coprolite S4-4, showing upper leaf epidermis with remains of trichomes (no further identification).

Seeds of white water-lily (*Nymphaea alba*) and crab apple (*Malus sylvestris*)

The remains of white water-lily (*Nymphaea alba*) seeds were present in four coprolites: S3-10 (in Fig. 8.12 a), S3-11, S3-20 and S3-28. The seeds of this water plant are ovate in outline and more or less circular in cross-section. They have a characteristic cell pattern of their testa which allows specific taxonomic identification even if only small fragments of the seeds are preserved in the archaeological record (Fig. 8.12 b). In one of the coprolites (S3-28) the seed remains of white water-lily were embedded in the coprolite matrix along with seed of apple (*Malus sylvestris*) (Fig. 8.13). The seeds of water-lily and the apple were also detected in the micro CT-scans (see Chapter 6).

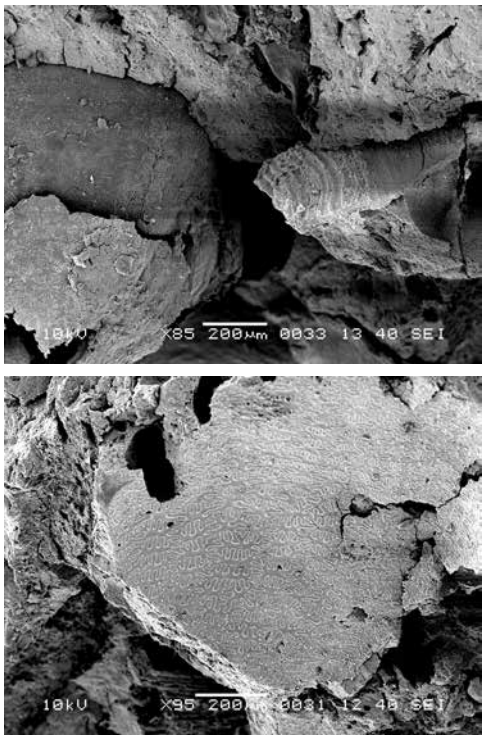


Figure 8.12 SEM images of the internal structure of the S3-10 coprolite showing seed remains of white water-lily (*Nymphaea alba*) embedded in the coprolite matrix. a. Overview, to the right of the seed, a fragment of fish scale is also visible; b. Detail showing, diagnostic for this species, seed testa with rows of rectangular cells with wavy cell walls.

8.4 Discussion and interpretation

The presence of reed stem fragments in one of the coprolites from Hardinxveld-Giessendam De Bruin (19952), defined as pig coprolite (Chapter 5), demonstrates the use of grass resources as animal fodder in the Late Mesolithic – Early Neolithic in the Lower Rhine-Meuse delta. Interestingly, this coprolite also contained numerous fish bone fragments and fish scales as well as duck bone remains embedded in its matrix (Chapter 7). It seems that the form of animal husbandry that was practiced at Hardinxveld-Giessendam De Bruin combined plant fodder (likely young reed stems and leaves) and domestic waste from food preparation. The presence of the charred herbaceous stem fragments also embedded in the 19952 coprolite suggests that the pigs were wandering around the cooking fires in search of waste from food

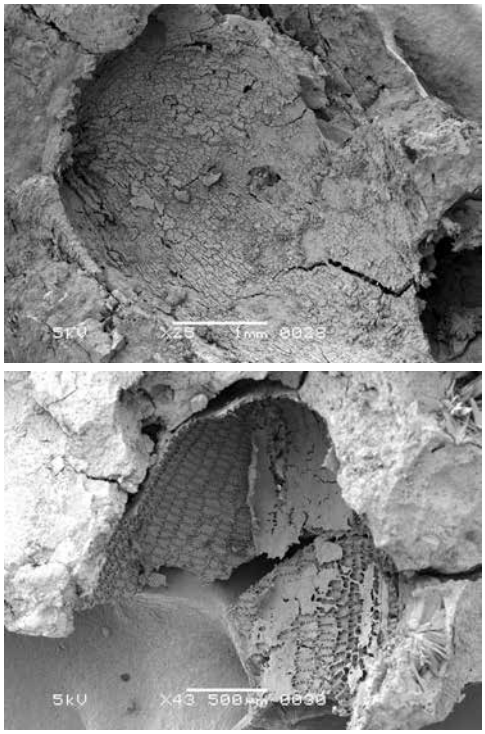


Figure 8.13 SEM images of the internal content of the S3-28 coprolite, showing remains of a. crab apple (*Malus sylvestris*) seed; and b. white water-lily (*Nymphaea alba*) seed embedded in the coprolite matrix.

preparation. This would further indicate that pigs were kept within the settlement. It is imaginable that reed was collected and used as animal fodder, rather than that the pigs had to forage in the marsh vegetation. In the Synthesis, we further discuss what information can be obtained from the analysis of coprolites of domestic animals and how this information can contribute to a discussion on prehistoric animal husbandry.

Some of the research questions of the project were related to the consumption of cereals. SEM evidence can be presented for the consumption of cereals at the Swifterbant –S3 and –S4. However, no SEM evidence for cereal consumption was found in the coprolite remains from Hardinxveld-Giessendam De Bruin.

The evidence of cereal chaff in the form of silicified epidermal tissue of emmer husks can be presented for five coprolites: three originating from human or likely human sources (S3-4, S3-28 and S4-1), one of likely pig origin (S3-2), and one of ruminant origin (S3-5). In all of the coprolites, emmer chaff was found together with remains of other food. The chaff remains would have entered the meals, and eventually the coprolite matrices, together with the grain. This can be explained by the fact that, particularly in glume cereals such as emmer wheat, some fine chaff particles of the husks (the lemma, the palea or the glumes) would always have survived the process of dehusking the grain and would have entered the meals (most likely the cooking pots) together with the grain. For this reason, emmer chaff epidermal tissue has often been observed in charred food residues encrusted on ceramic vessels.[139] In the case of naked barley, for example, the grain is released from the hulls at the early stage of the threshing process, so this cereal would have entered the cooking pots as truly clean grain, which might explain why the chaff of barley is only very seldom found in food residues.

The presence of mistletoe leaves in two coprolites, S3-8 (pig coprolite) and S4-4 (likely human/not specified), are of much interest. This semi-parasitic evergreen shrub grows on the stems and crowns of various deciduous and coniferous trees. Among the deciduous trees, it is commonly found on poplar, lime, apple and hawthorn (Fig. 8.14).[140] Even though neither the macroremains nor the pollen assemblages revealed the presence of mistletoe in the vicinity of the Swifterbant sites, this shrub must have grown in the region during the period of Swifterbant Culture occupation, as indicated by pollen of *Viscum album* recorded at the Early Neolithic Hoge Vaart-A27 site located some 35 km south of the Swifterbant area.[141] The presence of mistletoe leaves in two coprolites, of which one was defined by faecal steroids as pig coprolite (S3-8), suggests that the leaves and, possibly, the whole plant would have been collected and used as animal fodder. One of the scenarios could be that the evergreen twigs and leaves were used as winter fodder when other plant food was scarce. It is also possible that mistletoe plants were collected at some distance from the Swifterbant settlement. Both scenarios could explain the lack of pollen recovery. The use of mistletoe as animal fodder in prehistoric Europe was suggested earlier. At the Neolithic lakeshore settlement Arbon Bleiche 3 in Switzerland, remains of stems, twigs, leaves and berries of mistletoe were found in animal dung (including cattle dung); they were therefore interpreted as animal fodder.[142] The leaf remains of mistletoe were also found in animal dung

[139] Raemaekers *et al.* 2013; Kubiak-Martens *et al.* 2015a.
[140] Sebald *et al.* 1992.
[141] Hogestijn & Peters 2001.
[142] Jacomet, Leuzinger & Schibler 2005.

Figure 8.14 Mistletoe (*Viscum album*) growing on an apple tree (source: BIAX).

(including sheep/goat pellets) at two late Neolithic sites in Germany (Alleshausen-Täschenwiesen and Alleshausen-Grundwiesen) where they were also interpreted as animal fodder.[143]

Interestingly, there are more prehistoric sites and contexts where mistletoe remains were revealed. At the Neolithic pile dwelling in Hornstaad Hörnle on the shore of Lake Constance in Germany, mistletoe was found in human coprolites and was interpreted as a medicinal plant.[144] Mistletoe has various medicinal properties. It is used in both traditional and complementary medicine.[145] The medicinal properties are assigned to the leaves, stems and berries. Mistletoe has been used to treat various illnesses, including inflammation of the joints, asthma, diarrhoea and hepatitis infection.[146] As for the S4-4 coprolite with some initial signals for its human origin, we cannot completely exclude that mistletoe was used as a medicinal plant in Swifterbant tradition.

Five of the studied coprolites (S3-4, S3-5, S3-13, S3-18 and S3-20) share the presence of what are likely to have been knotgrass leaves. One of these coprolites (S3-20) was defined as human in the faecal steroid analysis (Chapter 5). This coprolite also contains remains of white water-lily seeds and fish and mammal bones (Chapters 6 and 7). In addition, phytoliths of cereal husk (likely barley) were found in the matrix of this coprolite (Chapter 9). The knotgrass leaves were also found in one likely-human coprolite (S3-18), and in two animal coprolites, one of which is of ruminant origin (cattle and/or sheep/goat) and the other likely derived from a dog (S3-5 and S3-13, respectively). This indicates that the leaves of knotgrass were consumed by people living on the S3 settlement, likely as green/leaf vegetables. The leaves and probably the complete young plants must also have been eaten by domestic animals when wandering freely through the settlement.

Knotgrass was one of the species well represented in the macroremains assemblages from the S3 site.[147] It was also present in the macroremains from the S4 site.[148] The high frequencies of seeds from the S3 macroremains assemblages suggest that the plant would have been quite common at and around the site. It would have grown along the paths where people and animals walked, and around the houses.

Many of the plants in the Polygonaceae family, including knotgrass, are edible and can be used as green vegetables. The young leaves and the whole knotweed plant can be eaten cooked or raw. The plant contains oxalic acid, giving the green parts a distinctive sorrel-like flavour. The whole plant also has various medicinal properties. It can be used for the treatment of parasitic diseases such as those caused by helminths and ectoparasites, among others. It can be used both internally and externally in the treatment of wounds and bleeding. Its diuretic properties make it useful in removing kidney stones.[149] The green leaves (Fig. 8. 15), presumably the young leaves, would

143 Kühn *et al*. 2013.
144 Maier 2001.
145 Moerman 1998.
146 Boyer & Lindor 2016.
147 Van Zeist & Palfenier-Vegter 1981.
148 Schepers & Bottema-Mac Gillavry 2020.
149 *https://pfaf.org.*

have been collected either for food or their medicinal properties - or possibly for both.

White water-lily seeds were the dominant component in two coprolites (S3-10 and S3-11). The overwhelming presence of the seeds through the matrix of both coprolites is well illustrated in the micro-CT scans (Chapter 6). It is clear from these images that the seeds were the main component of the meal, consumed, possibly, with the addition of fish, as suggested by the fish bones and fish scales that accompanied the water-lily seeds (Chapter 6). Usually, the testa of the empty seeds was preserved, often deformed but still revealing the outline of the individual seeds. Also, many seed fragments were embedded in both coprolite matrices. In S3-20 (human coprolite) and S3-28 (likely-human coprolite), the white water-lily seeds were also present, but were represented only by a few seed remains embedded in the coprolite matrices.

Interestingly, the seeds of white water-lily were remarkably well represented in the waterlogged macroremains assemblages from the S3 site. Most of the seeds were damaged in varying degrees, and they were concentrated at a considerable distance from what seemed to be the activity areas of the S3 settlement.[150] *Nymphaea alba* is a typical fresh-water species that would have been found in freshwater stream channels or creeks and the lowermost parts of the back-swamp areas with permanent open water. Ripe seed pods (capsules) would have been collected in late summer until early autumn for their edible seeds.

There is good evidence from prehistoric sites across Europe, including in the Netherlands, of white water-lily seeds and closely related species being used as food. The seeds of all water-lilies are edible and contain much starch, protein and oils, as well as some sugars. An example in point is the Late Mesolithic site Halsskov on the Danish island of Zealand, where seeds of the closely related species, the least water-lily (*Nuphar pumilum*), were encountered in features interpreted as cooking pits.[151] Also of much interest in this respect are the many charred seeds of yet another closely related species, the yellow water-lily (*Nuphar lutea*), found together with charred white water-lily seeds and other edible plant foods in surface hearths at the Early Neolithic Swifterbant Culture site at Hoge Vaart-A27 in the Netherlands. They were interpreted as intentionally collected and most likely used as food.[152]

Figure 8.15 Knotgrass (*Polygonum aviculare*) as it appears in early summer (source: BIAX).

There are various methods described in the ethnographic literature for processing water-lily seeds, as some indigenous peoples in North America consumed the seeds extensively. The best example we know about is from the Klamath Indians who lived along the shores of the Klamath River and the Klamath Lake in Oregon (USA).[153] The seeds of the water-lily (*Nymphaea polysepala*) provided a staple food for the tribe. The Klamath used their canoes to harvest the seed pods of the water-lily (Fig. 8.16). They gathered enormous quantities of the seed pods during July and August. To extract the seeds from the pods, it was common to dig a pit beside the lake or river and leave it to fill with

[150] Van Zeist & Palfenier-Vegter 1981.
[151] Kubiak-Martens 2002.
[152] Brinkkemper *et al.* 1999.
[153] Buan & Lewis 1991.

water, then lower the baskets with water-lily seed pods (capsules) into the pit and let the pods ferment. Once fermentation was completed, the seeds were washed clean of rotted capsule fragments. The dried seeds had their coat (testa) removed and then were winnowed and parched. The seeds were eventually ground into meal or flour (in rock mortars) and made into a porridge or bread. The Klamath utilised a distinctive two-horned milling stone to hull the water-lily seeds.

One can wonder whether the concentrations of damaged white water-lily seeds found at a distance from the settlement/(domestic) activity area at the Swifterbant-S3 site may suggest an area where the seeds were processed. It is difficult to say whether the seeds were cooked or eaten raw but it is clear that they were used in the traditional Swifterbant diet and that their consumption likely originated in the Mesolithic tradition of this culture.

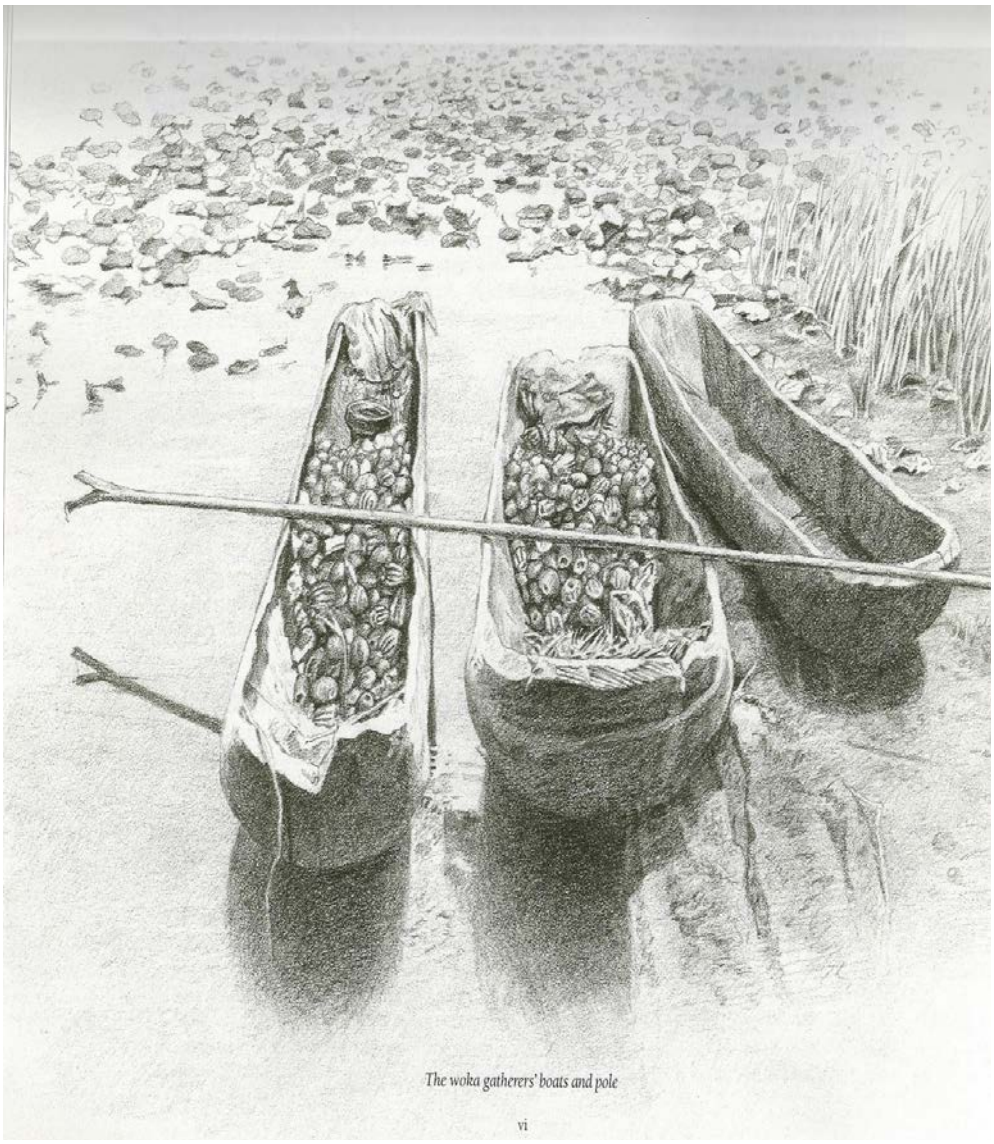


Figure 8.16 The shore of the Klamath Lake with canoes loaded with water-lily seed pods (source: Buan & Lewis 1991). In the same way, the seed capsules of white water-lily could have been gathered by the Swifterbant people in the wetlands of current Flevoland.

Table 8.1. The results of the SEM analysis.

Coprolite code	Sample number	SEM results
Hardinxveld	7552	no data
Hardinxveld	19520	herbaceous stem tissue (possibly grass)
Hardinxveld	19952	likely Phragmites stem epidermis with long cells accompanied by gramineous type stomata and few papillae
S3-2	54516	silicified epidermal tissue likely of emmer chaff accompanied by numerous papillae/ trichome scars; epidermal surface, likely from emmer glumes, showing numerous papillae accompanied by gramineous-type stomata; numerous fragments of herbaceous leaves/stems (including some parenchyma)
S3-4	54655	silicified epidermal tissue from emmer chaff (lemma or palea); Phragmites leaf (epidermal tissue); herbaceous leaf fragments (indet.), leaf fragments of cf. Polygonum aviculare
S3-5	51179	silicified emmer husks (imprints of epidermal cells), silicified epidermal tissue-likely Phragmites stem (culm) with numerous papillae and gramineous type stomata (the same tissue as in S3-2), herbaceous leaf fragments (cf. Polygonum aviculare - the same tissue as in S3-13 and S3-18)
S3-8	53985	leaf remains of Viscum album with epidermal tissue and stomata (the same tissue as in S4-4); herbaceous leaf fragments with trichomes and trichome scars (the same tissue as in S4-4)
S3-10	54845	numerous seeds of white water-lily (Nymphaea alba)
S3-11	54827	numerous seeds of white water-lily (Nymphaea alba)
S3-12	53842	herbaceous stem/leaf tissue; possible parenchyma cells, indet.
S3-13	53814	numerous leaf fragments of cf. Polygonum aviculare, rolled (the same tissue as in S3-5, S3-18, S3-20)
S3-15	43716	silicified epidermal tissue, likely of Phragmites stem (culm); indet. herbaceous leaf/stem
S3-18	54752	leaf fragments of cf. Polygonum aviculare (the same tissue as in S3-5, S3-13, S3-20)
S3-19	57328	no data
S3-20	57443	white water-lily (Nymphaea alba), leaf fragments of cf. Polygonum aviculare (the same tissue as in S3-5, S3-13 and S3-18); indet. herbaceous stem/leaf tissue
S3-23	54240	no data
S3-26	53954	herbaceous stem/leaf tissue, indet.; diatoms
S3-27	54052	no data
S3-28	54488	silicified epidermal tissue-likely emmer chaff epidermis, crab apple (Malus sylvestris) and white water-lily (Nymphaea alba) seeds; diatoms
S3-29	45691	no data
S4-1	1420	silicified epidermal tissue from emmer chaff (lemma or palea); Phragmites leaf (epidermal tissue with gramineous type stomata)
S4-3	1366	no data
S4-4	629	leaf remains of Viscum album with epidermal cells and multiple stomata (the same tissue as in S3-8); indet. herbaceous leaf fragments with trichomes and trichome scars (the same tissue as in S3-8)
J78 91-2	1177	no data
J78 91-1	1184	no data

8.5 Conclusions

SEM analysis of the coprolite samples provided a way to depict diverse dietary components in the diet. In some cases, the SEM showed different elements in a single image of the internal microstructure of the coprolite, revealing the complexity of the diet. In the SEM examinations, the evidence for the consumption of cereals was generally sparse. This, however, can be (partially) related to the fact that only tiny particles of chaff survived the cereal processing and cooking, and the evidence might be more compelling than it seems. The SEM analysis indicates that the cereals were likely used as an addition to other foods. The absence of particles of cereal grain suggests that they would have had less of a chance to survive the processes of food preparation and digestion. In the SEM images, the evidence of cereal consumption consists of particles of emmer chaff, which would have entered the food preparations together with the grain. Whether the food was a porridge-like meal prepared in cooking pots or other emmer-based products, cannot be deduced from the remains preserved in the coprolite matrices.

The high density of white water-lily seeds in some of the studied coprolites (sometimes accompanied by other foods like crab apple and cereal) suggests that water-lily with its starch and protein-rich seeds can be interpreted as a food source.

A significant addition to the study of past human and animal diets was the identification of vegetative plant parts. Often, the only statement that can be made about masticated leaf fragments from coprolites is that they were from a monocotyledon or dicotyledon plant. In the study presented here, the SEM images enabled the identification of at least two different green vegetables that could have been used in the Swifterbant human (and animal) diet. These were knotgrass leaves and stems of reed, the latter likely consumed as young shoots, possibly by both humans and domestic animals. Mistletoe could have been used as animal fodder but also as a medicinal plant. Many more herbaceous plants and their green parts would have been used, in human and animal diets but unfortunately, we cannot name them all.

9 Phytoliths

L.-M. Shillito

9.1 Introduction

Phytoliths are composed of biogenic silica and form within and between the cells of plants, forming three-dimensional mineral replicas of the cell structure. When a high degree of silicification occurs, they can form very large sections of plant tissue. In other cases only single cells are silicified. Larger tissue fragments can be used to identify the genus of plants, based on the cell morphology. When only single cells preserve, they can be identified at a broader taxonomic level as coming from monocotyledonous or dicotyledonous plants, or from a C3 or C4 plant.[154] The degree to which plants become silicified varies according to the amount of water available during growth, the amount of silica in the growth substrate and the degree of evapotranspiration.[155] Certain parts of the plant epidermis, such as the short cells, become silicified first, followed by long cells. In temperate environments, it is more common to find single cell types with Poaceae being amongst the most common types observed.[156]

Over the past decade, there has been an increasing number of studies of phytoliths from animal dung, for example, to look at foddering practices.[157] For animals that have consumed large quantities of grasses, fragments of plant tissue can preserve in their dung. There have been few studies looking at phytoliths from human coprolites. Human coprolites in archaeological contexts can be highly variable in appearance and content, depending on the environments in which people lived and the preservation conditions, as well as the diet during the period faeces is produced. Phytoliths observed in coprolites tend to be single-celled or smaller conjoined types which may show a high degree of erosion from digestive processes.[158]

A total of 13 coprolites were subsampled for phytolith analysis (see Tables 9.1 and 9.2). The aims of this analysis are to assess the dietary information in coprolites from Neolithic Swifterbant sites excavated before 2007. The results of the analysis of phytoliths presented here are combined with those from other analyses to provide a multi-proxy reconstruction of the past diet.

9.2 Methods

Samples were processed according to Newcastle University Wolfson archaeology laboratory Standard Operating Procedure SOP1: phytolith extraction from archaeological samples. This is a six stage process. In summary, this involves the removal of carbonates using hydrochloric acid (HCl), removal of clays by settling with sodium hexametaphophate (NaPO3)6), removal of organic material by heating in a muffle furnace for two hours at 500°C, and separation of phytoliths from other mineral material by centrifugation with sodium polytungstate solution calibrated to 2.3 g cm-3. Samples were analyzed and counted using a compound microscope Leica DM750P at 400x magnification. Images were captured using an integrated ICC50W camera. Measurements were made using LAS EZ software.

Slides are prepared by mounting a known weight onto a 22 x 22mm mounted slide. At a magnification of 400x there are 48 fields of view in one 22-mm transect of the slide, which equals 2304 total fields of view on the slide. Quantities are estimated by counting 100-300 phytoliths across a known number of transects. As the total number of fields of view is known, the number of phytoliths per slide is calculated. Following this, an estimation of the numbers of phytoliths per gram of sediment can be estimated using the calculation: (number per slide/mass mounted (mg) x total extracted (mg)/total sediment weight (mg) x 1000.

9.3 Results

9.3.1 Phytolith preservation and quantity

Many of the samples show remarkably good phytolith preservation. The quantity of phytoliths recovered is highly variable, with some samples having very few to no phytoliths recovered, and others consisting of almost 500,000 phytoliths per gram (Fig. 9.1). This degree of variability is similar to observations of coprolite assemblages from other sites, where plants are thought to have constituted a large

154 Shillito 2021.
155 Shillito 2013.
156 Wade *et al.* 2021.
157 Portillo, García-Suárez & Matthews 2020; García-Suárez, Portillo & Matthews 2018.
158 Shillito *et al.* 2020a.

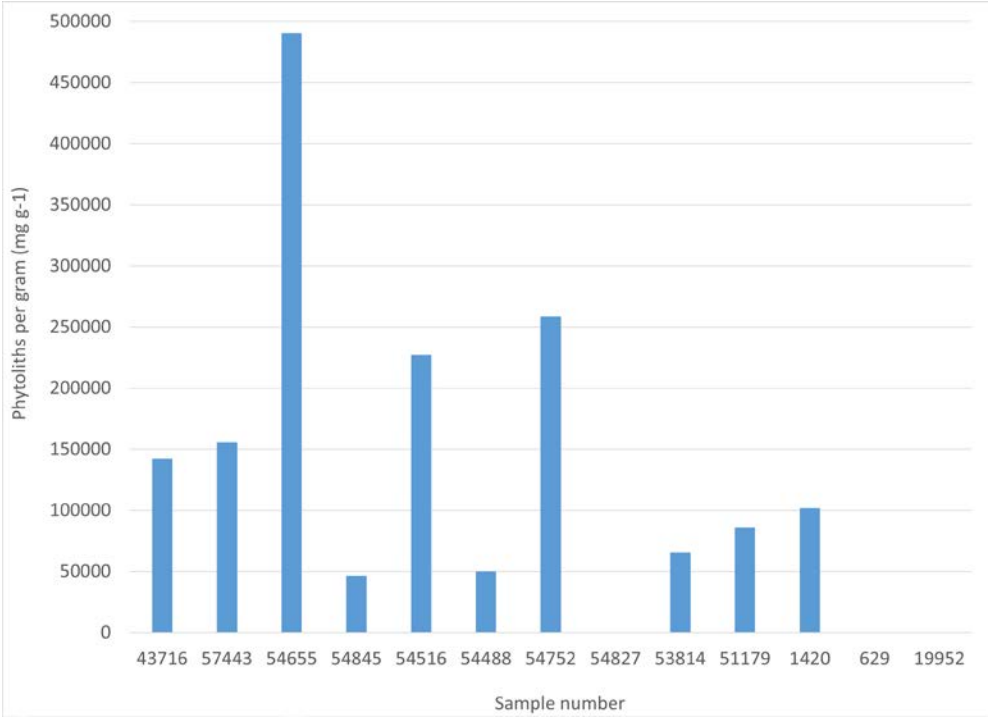


Figure 9.1 Bar chart showing numbers of phytolith per gram of coprolite.

proportion of the diet. For example, at the early prehistoric site of Paisley Caves, Oregon (USA), where the diet indicates people relied heavily on wetland resources, phytolith densities have ranged from 119 to 476,370 phytoliths per gram of coprolite.[159]

One aspect to note is that inclusions in coprolites often have a 'digested' appearance from passive through the digestive system, with some degree of weathering and pitting apparent. In the samples examined here, such weathering was not always visible, and in some samples, the phytoliths showed no evidence of digestion. The impact of digestion on phytoliths and other types of microfossils is an aspect that is still poorly understood and could be explored further.

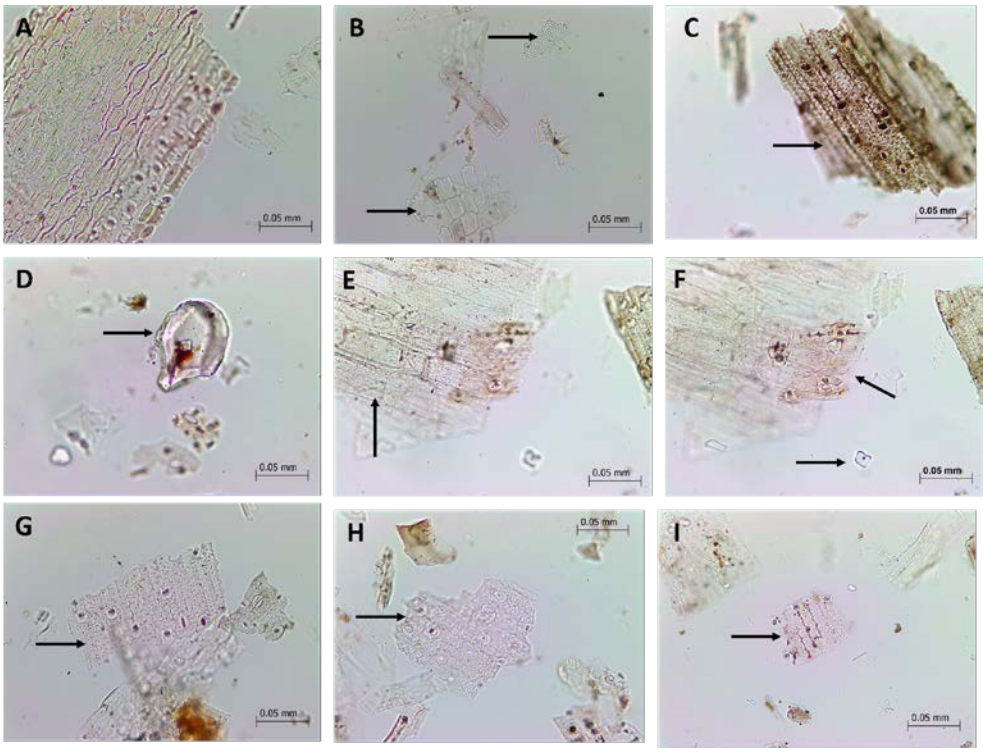


Figure 9.2 Phytoliths from coprolites S3-15 (a-g) and S3-18 (h-i). a. *Phragmites* leaf showing stomata; b. single smooth long cell (1) and conjoined polyhedral tissue (2); c. *Phragmites* stem; d. Keystone bulliform from *Phragmites*; e. showing barley husk (1) underlying a fragment of sedge tissue and saddle short cell (2); f. same image as e.focusing on the barley husk; g. wheat husk (1) and *Phragmites* leaf/stem (2); h. *Phragmites* stem (1), centric diatom (2) and *Phragmites* leaf (3).

[159] Blong *et al.* 2020.

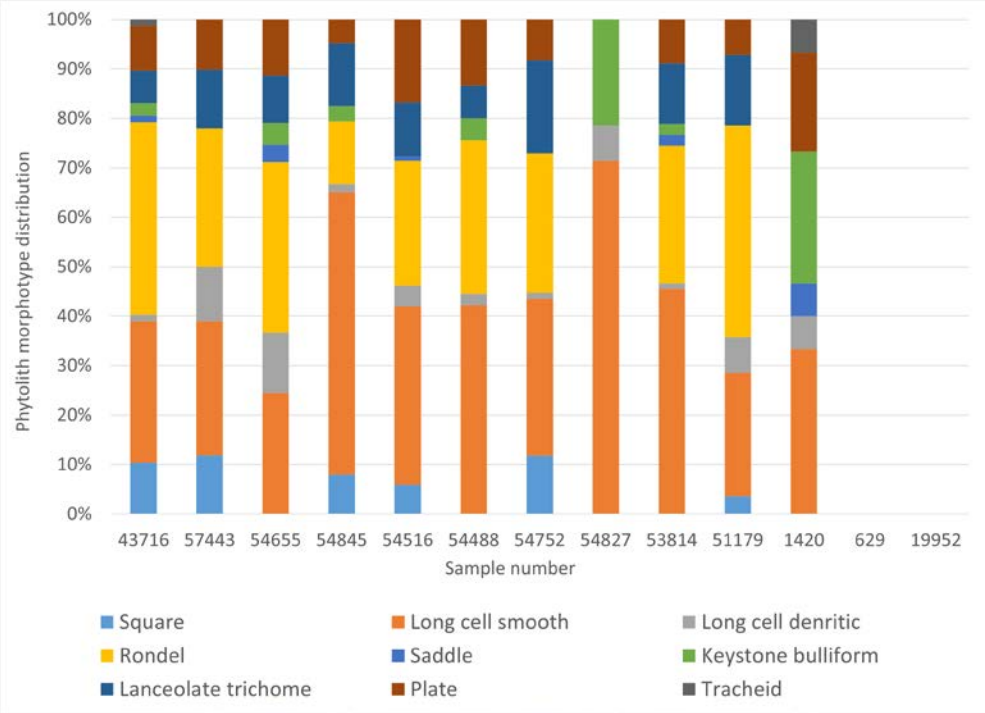


Figure 9.3 Stacked bar chart showing distribution of single cell phytolith morphologies in the coprolites.

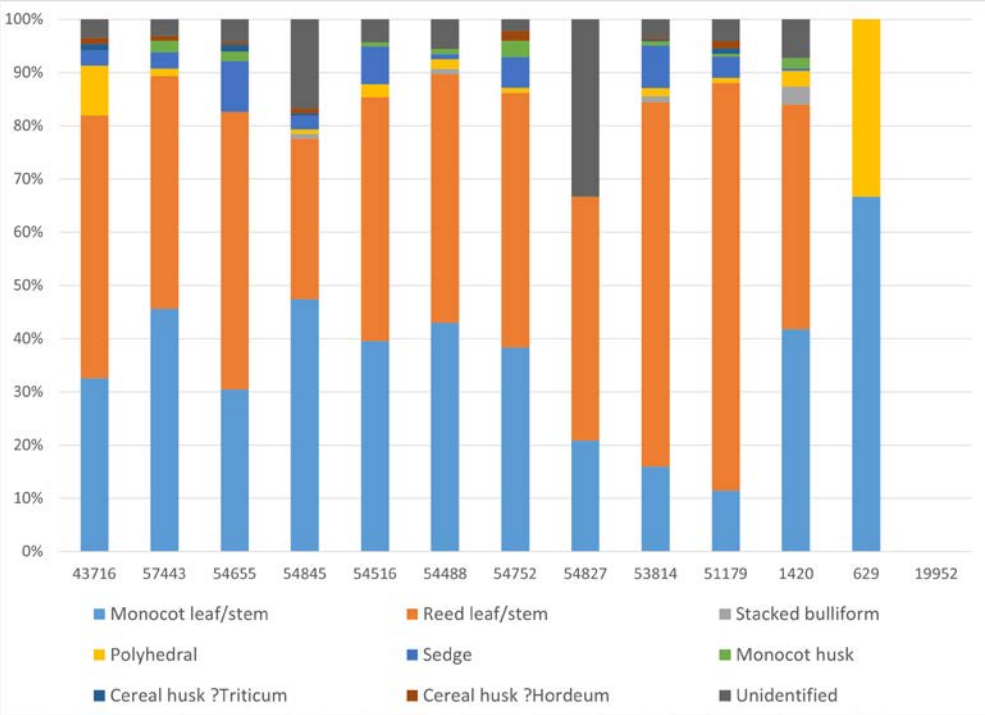


Figure 9.4 Stacked bar chart showing distribution of conjoined/multi-cell phytolith morphologies in the coprolites.

9.3.2 Phytolith morphotypes

Examples of morphotypes are shown in Fig. 9.2, whereas the distribution of single and conjoined morphotypes is shown in Fig. 9.3 and Fig. 9.4. Large fragments of conjoined tissue, exclusively from monocotyledonous plants, dominate the assemblages as no phytoliths from dicotyledonous plants were observed. Many of these are non-diagnostic tissues that can be classified as general monocotyledonous leaves and stems, others are large fragments of tissue that can be identified as reed (*Phragmites*), and, less abundantly, belonging to the sedge family (Cyperaceae). The extent of silicification of all phytoliths observed indicates the plants grew on favourable substrate for phytolith formation, characterized by high evapotranspiration. The preserved tissue fragments of reed are very large, with entire sections of stem being preserved, including hairs attached in situ, with a three-dimensional structure. Other conjoined types include frequent polyhedral conjoined phytoliths which likely represent mesophyll tissues.

There are occasional husk phytoliths present, including a very small number that compare well with wheat and barley husks. These are also highly silicified with large tissue fragments preserved, suggesting that these cereals were growing in conditions of high water availability.[160] It should be noted that the unequivocal identification of phytoliths to species requires the preservation of both the wave pattern and papillae.[161] In these examples, the wave pattern is present, but papillae were sometimes difficult to make out, hence why these are classified as 'compares favourably' to the genus rather than a specific species.

9.3.3 Single-celled types and conjoined types

The number of conjoined types is much higher than the number of single-celled types, which is an atypical pattern (Fig. 9.5). It is more common to see a large number of single-celled types, with fewer large tissue fragments. The exceptionally large fragments seen in some of these samples are unexpected, given that these tend to break up very easily after deposition. Given the context (coprolites), a much higher degree of fragmentation would be expected.

9.3.4 Other inclusions

Few sponge spicules and diatoms were observed in most of the samples. Some samples also contained a small number of biogenic silica aggregates with a vesicular appearance, which appears similar to melted silica aggregates that are observed in deposits associated with burning. Although phytoliths are composed of silica and have a high melting point, this can be lowered substantially in the presence of alkali salts and leads to the melting of phytoliths and other biogenic silica particles.[162]

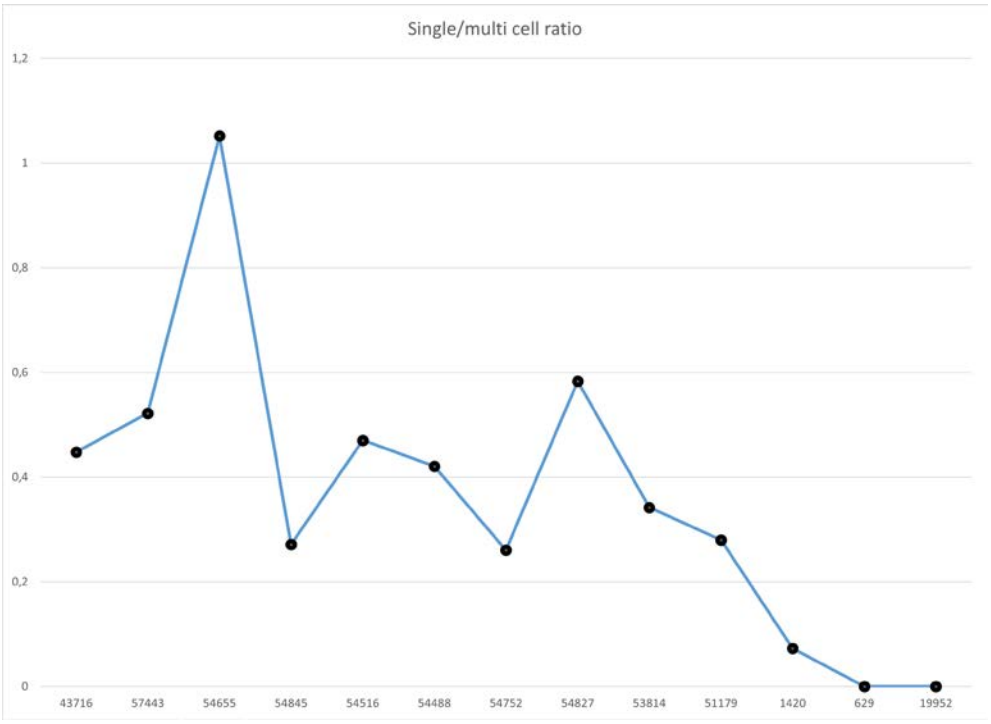


Figure 9.5 Ratio of single to conjoined types in each sample.

160 Shillito *et al.* 2011.
161 Rosen 1995.
162 Phytolith-derived molten silica is very common in Late Neolithic and (especially) Bronze Age sites to the west of Swifterbant (West Friesland) and in the Iron Age-Medieval terp sites in the northern coastal area of the Netherlands. In the Swifterbant S4 thin sections it is very rare, but occasionally noticed (pers. comm. Huis Huisman).

Table 9.1 Sample descriptions.

Sample	Coprolite code	Site	Quality assessment	total mass (mg)	phytolith mass (mg)	amount mounted (mg)
19952		Hardinxveld-Giessendam De Bruin	No phytoliths, some minerals	709,7	1,4	0,5
54516	S3-2	Swifterbant S3	Large quant of highly silicifed, large conjoined reeds, grasses	1083,2	24,8	1,8
54655	S3-4	Swifterbant S3	Lots of reeds etc but seem to be more fragmented. More noticeable number of shirt cells than others	535,9	11,6	0,5
51179	S3-5	Swifterbant S3	Large quant of highly silicifed, large conjoined reeds, grasses	214,5	1,8	0,6
54845	S3-10	Swifterbant S3	Large quantity of phytoliths, fragmented and broken, brown staining	917,4	3,6	1,2
54827	S3-11	Swifterbant S3	Few, digested, grasses	157,0	<0.5	<0.5
53814	S3-13	Swifterbant S3	Large quant, highly silicifed,	260,3	1,2	0,9
43716	S3-15	Swifterbant S3	Large quant of highly silicifed, large conjoined reeds, grasses. Very clean sample.	915,4	10,9	1,0
54752	S3-18	Swifterbant S3	Large quant of highly silicifed, large conjoined reeds, grasses, charcoal. Very clean.	274,8	3,6	1,0
57443	S3-20	Swifterbant S3	Large quant of highly silicifed, large conjoined reeds, grasses, husks? Very clean.	994,2	17,8	1,9
54488	S3-28	Swifterbant S3	Large quant, highly fragmented, some eroded, brown staining	532,4	5,1	1,4
1420	S4-1	Swifterbant S4	Lots of melted silica, large quant silicifed phytoliths, some appear eroded, staining	428,5	3,7	0,9
629	S4-4	Swifterbant S4	Very few, digested, grasses	181,2	<0.5	<0.5

Table 9.2 Phytolith counts.

Site	Swifterbant S3					
Sample number	**43716**	**57443**	**54655**	**54845**	**54516**	**54488**
Coprolite code	**S3-15**	**S3-20**	**S3-4**	**S3-10**	**S3-2**	**S3-28**
Producer (GC-MC)	**pig**	**human**	**carnivore/human**	**carnivore/human**	**pig**	**human/ruminant**
SINGLE						
Square	8	14	0	5	7	0
Long cell smooth	22	32	56	36	43	19
Long cell denritic	1	13	28	1	5	1
Rondel	30	33	79	8	30	14
Saddle	1	0	8	0	1	0
Keystone bulliform	2	0	10	2	0	2
Lanceolate trichome	5	14	22	8	13	3
Amorphous/unidentified	0	0	13	0	0	0
Plate	7	12	26	3	20	6
Tracheid	1	0	0	0	0	0
Total	**77**	**118**	**242**	**63**	**119**	**45**
CONJOINED						
Monocot leaf/stem	56	103	70	110	100	46
Reed leaf/stem	85	99	120	70	116	50
Stacked bulliform	0	0	0	2	0	1
Polyhedral	16	3	0	2	6	2
Sedge	5	7	22	6	18	1
Monocot husk	0	5	4	0	2	1
Cereal husk ?Triticum	2	0	3	1	0	0
Cereal husk ?Hordeum	2	2	1	2	0	0
Unidentified	6	7	10	39	11	6
Total	**172**	**226**	**230**	**232**	**253**	**107**
OTHER						
Melted silica aggregate	0	0	2	5	0	6
Sponge spicules	5	0	4	2	0	2
diatoms	4	2	3	3	0	4
TOTAL	**249**	**344**	**472**	**295**	**372**	**152**
FoV counted	1	1	2	1	1	1
Mass mounted (mg)	1,0	1,9	0,5	1,2	1,8	1,4
Total extracted (mg)	10,9	17,8	11,6	3,6	24,8	5,1
Total sediment weight (mg)	915,4	994,2	535,9	917,4	1083,2	532,4
Phytoliths per slide	11952	16512	11328	14160	17856	7296
Phytoliths per gram (mg g-1)	142316,8014	155593,8125	490407,9119	46304,77436	227119,6455	49921,6486
Single/multi cell ratio	0,447674419	0,522123894	1,052173913	0,271551724	0,470355731	0,420560748

n.d.=faecal steroids not detected

				Swifterbant S4		Hardinxveld-Giessendam De Bruin
54752	54827	53814	51179	1420	629	19952
S3-18	S3-11	S3-13	S3-5	S4-1	S4-4	
n.d.	not faecal	poss. carnivore	ruminant?	n.d.	n.d.	pig
10	0	0	2	0	0	0
27	10	41	14	5	0	0
1	1	1	4	1	0	0
24	0	25	24	0	0	0
0	0	2	0	1	0	0
0	3	2	0	4	0	0
16	0	11	8	0	0	0
0	0	0	0	0	0	0
7	0	8	4	3	0	0
0	0	0	0	1	0	0
85	**14**	**90**	**56**	**15**	**0**	**0**
125	5	42	23	86	2	0
156	11	180	153	87	0	0
0	0	3	0	7	0	0
3	0	4	2	6	1	0
19	0	21	8	1	0	0
10	0	2	1	4	0	0
0	0	1	2	0	0	0
6	0	1	3	0	0	0
7	8	9	8	15	0	0
326	**24**	**263**	**200**	**206**	**3**	**0**
0	7	5		12	0	0
1	0	3		1	0	0
0	1	8		2	0	0
411	**38**	**353**	**256**	**221**	**3**	**0**
1	1	1	1	1	all	all
1,0	0,5	0,25	0,6	0,9	0,5	0,5
3,6	0,5	0,5	1,8	3,7	0,5	1,4
274,8	157,0	517	214,5	428,5	181,2	709,7
19728	38	16944	6144	10608	3	0
258445,4148	242,0382166	65547,38878	85930,06993	101775,1848	16,55629139	0
0,260736196	0,583333333	0,342205323	0,28	0,072815534	0	0

9.4 Discussion and recommendations

The concentration and preservation of phytoliths in the studied coprolite samples is remarkable, and has not previously been observed in coprolites to the best of our knowledge. The study on coprolites by Blong *et al.* also showed abundant phytoliths. However, these are typically more fragmented in coprolites than those observed in the coprolites from the Swifterbant Culture.[163]

The degree of silicification is high and size of conjoined phytoliths in the Swifterbant coprolites is large. It has previously been suggested that temperate sites in Northwestern Europe do not provide the most favourable conditions for phytolith formation, and that phytolith assemblages from these regions typically include single-cell forms, as well as tissues where silicification is not as extensive.[164] This suggests that factors such as evapotranspiration may be less important than water availability and soil substrate in determining the extent of phytolith formation. Additionally, it indicates that phytolith analysis in temperate regions is certainly worth pursuing.

The presence of large quantities of reed is interesting. Reed shoots are edible if harvested early, before they start to turn woody. Their ubiquity in the coprolites would certainly suggest that these were being consumed. However, one aspect that also must be considered, is the extent to which these samples reflect active consumption. Phytoliths recovered from omnivore coprolites are typically much smaller and have a 'digested' appearance, and that is rarely observed in these samples. That being said, the impact of omnivore digestion on phytoliths has not been fully explored, and there is no reason to doubt that these come from ingested material, given the care that was taken to avoid sampling the outer surface where contamination could potentially have occurred.

It is unclear whether the variability in phytolith concentration in each sample is a result of preservation or other factors. One observation is that some samples contain small amounts of melted silica aggregates. These have a very distinctive vesicular or 'bubbly' appearance.[165] These are observed in samples S3-11, S3-28, S3-11, and S4-1. It is unclear whether these silica aggregates are derived from material that has been ingested in this state, or if the coprolite has been subjected to heat post-depositionally.

Given the high concentration of phytoliths, it is certainly worth pursuing this type of analysis in future studies. Whilst many of the phytoliths were classified as derived from leaves or stems of grass in general, perhaps future analysis using a reference collection of wild grasses from the region would allow further identification to genus level.

[163] Blong *et al.* 2020.
[164] Wade *et al.* 2021.
[165] Canti 2003; Matthews 2016.

10 Pollen and other microfossils

M. van der Linden

10.1 Introduction

Human coprolites are rarely found in the Netherlands. Therefore, in comparison with other types of archaeological finds, only a few coprolites from Dutch sites have been subjected to palynological research in the past. Since coprolites are fossilised faeces produced by humans or animals, the pollen composition of these coprolites provides information on the diet of the producers and the environment they inhabited.

10.2 Methods

10.2.1 Sample preparation

The coprolites selected for palynological research were subsampled in the laboratory of BIAX Consult by selecting small pieces of gently cleaned and crushed, dry, untreated coprolite material from the samples that were first analysed for macroremains (see Table 10.1).[166] The volume (ml) and weight (g) were determined for all of the subsamples. The subsamples were sent to the laboratory of the University of Amsterdam, where the slides for compound microscopy were prepared. The samples were treated following Erdtman's methodology for pollen preparation.[167] The residues remaining on the 150 µm mesh sieve were collected and scanned for macrofossil remains using a stereo microscope.[168] The residues with smaller microfossils were used for pollen slide preparations. Since the first slides of the prepared samples contained a large amount of inorganic matter, the residues were sieved one extra time over an 8 µm mesh sieve to remove the smallest particles. In total, five to seven slides per sample were analysed. To calculate the pollen concentrations, a known quantity of common club moss (*Lycopodium clavatum*) spores was added to each sample.

10.2.2 Microscopic analysis

The palynological analysis was performed using compound light microscopy (Olympus BX41) with a maximum magnification of 1000x. All slides were analysed. During the analysis the number of pollen grains and spores of mosses, horsetails and ferns, and other microfossils (non-pollen palynomorphs such as fungal spores and algal remains) were quantified. Pollen and spores were identified using Moore, Webb and Collinson, Beug, the North European Pollen Flora Volumes I–IX (Punt *et al.*) and the reference collection at BIAX Consult.[169] Non-pollen palynomorphs were identified using Van Geel.[170]

Table 10.1 Sample data of the palynologically analysed coprolites.

Sample	Find	Material	Producer (GC-MC)	Volume (ml)	Labcode	Lycopodium (n)
Hardinxveld	19952	coprolite	pig	3	BX9300	17461
S3-2	54516	coprolite	pig	3	BX9099	18583
S3-4	54655	coprolite	carnivore/human	3	BX9295	17461
S3-5	51179	coprolite	ruminant?	0,5	BX9296	17461
S3-10	54845	coprolite	carnivore/human	3	BX9100	18583
S3-11	54827	coprolite	not faecal	3	BX9101	18583
S3-13	53814	coprolite	poss. Carnivore	3	BX9297	17461
S3-15	43716	coprolite	pig	3	BX9102	18583
S3-18	54752	coprolite	n.d.	0,8	BX9103	18583
S3-20	57443	coprolite	human	3	BX9104	18583
S3-28	54488	coprolite	human/ruminant	3	BX9298	17461
S4-1	1420	coprolite	n.d.	3	BX9299	17461
S4-4	629	coprolite	n.d.	0,3	BX9105	18583

166 Before the macrofossil analysis the coprolites were cleaned on the outside to avoid contamination with recent and subrecent material. Some of the coprolites were covered with ash.
167 Erdtman 1960.
168 The small macroremains did not bring extra information to this study than already shown by the other proxies.
169 Beug 2004; Moore, Webb & Collinson1991; Punt *et al.* 1976-2009.
170 Van Geel 1976.

The nomenclature of the microfossils follows this identification literature.[171] The percentage calculations were based on a total pollen count of the slides prepared for pollen analysis.

10.2.3 Interpretation of the pollen assemblages

The pollen types were assigned to ecological groups to aid the diet and environmental reconstructions. Ecological preferences were assessed using Dutch ecological literature.[172] As the pollen counts in some of the coprolites were very low, the percentages of specific taxa are only cautiously interpreted as indicative of the approximate composition of the vegetation near the settlement. Since pollen enters the faeces (coprolites) via the ingestion of food and water and the inhalation of air, the pollen assemblage may not represent the entire natural surrounding vegetation but may be biased towards food plants and/or local vegetation. In addition, the formation of faeces is a quick process. The pollen composition in coprolites may, therefore, be affected by seasonality and the resulting pollen production of certain plant species.[173]

To interpret pollen data from natural deposits, the ratio between arboreal and nonarboreal pollen is often used to explain the degree of openness of the vegetation. To indicate the openness of the vegetation near the settlement, the ratio between arboreal and nonarboreal pollen was based on the study of Groenman-Van Waateringe.[174] This study on pollen rain in recent vegetation showed that arboreal pollen percentages of less than 25% indicated an open landscape. Arboreal pollen percentages higher than 55% indicated a forested landscape, while arboreal pollen percentages ranging between 25 and 55% indicated open forest or forest edges.[175] In the case of coprolites, in which pollen also enters with food and drink, this can be used in a general sense only. More important, the known ecological amplitude of plant species and other microfossils was used to interpret the local environmental setting. The edibility of plants and their medicinal use was also taken into account. To place the pollen data of the coprolites into the larger environmental setting, the pollen data of the coprolites was compared with vegetation reconstructions based on pollen studies of natural deposits from the sites of Hardinxveld-Giessendam De Bruin and Swifterbant S3 and S4.[176] In addition, the coprolite pollen data was compared to pollen data from other coprolites from Hardinxveld-Giessendam De Bruin (Late Mesolithic-Early Neolithic), Hekelingen (Late Neolithic), and Schipluiden-Harnaschpolder (Middle Neolithic).[177]

171 Beug 2004; Moore, Webb & Collinson 1991; Punt *et al.* 1976-2009, Weeda *et al.* 1985-1994.
172 Weeda *et al.* 1985-1994; Tamis *et al.* 2004; Van der Meijden 2005.
173 Vermeeren & Kuiper 1993, 213-220. The outer material of the coprolites is removed before analysis to make sure no younger pollen than that of the faeces themselves was analysed.
174 Groenman-Van Waateringe 1986.
175 Groenman-Van Waateringe 1986, 197.
176 Hardinxveld-Giessendam De Bruin: Bakels, Van Beurden & Vernimmen 2001; Swifterbant S3: Van Zeist & Palfenier-Vegter 1981; Swifterbant S4: Schepers & Woltinge 2020.
177 Hardinxveld-Giessendam De Bruin: Bakels, Van Beurden & Vernimmen 2001; Hekelingen: Bakels 1988, Vermeeren & Kuiper 1993; Schipluiden-Harnaschpolder: Bakels 2006.

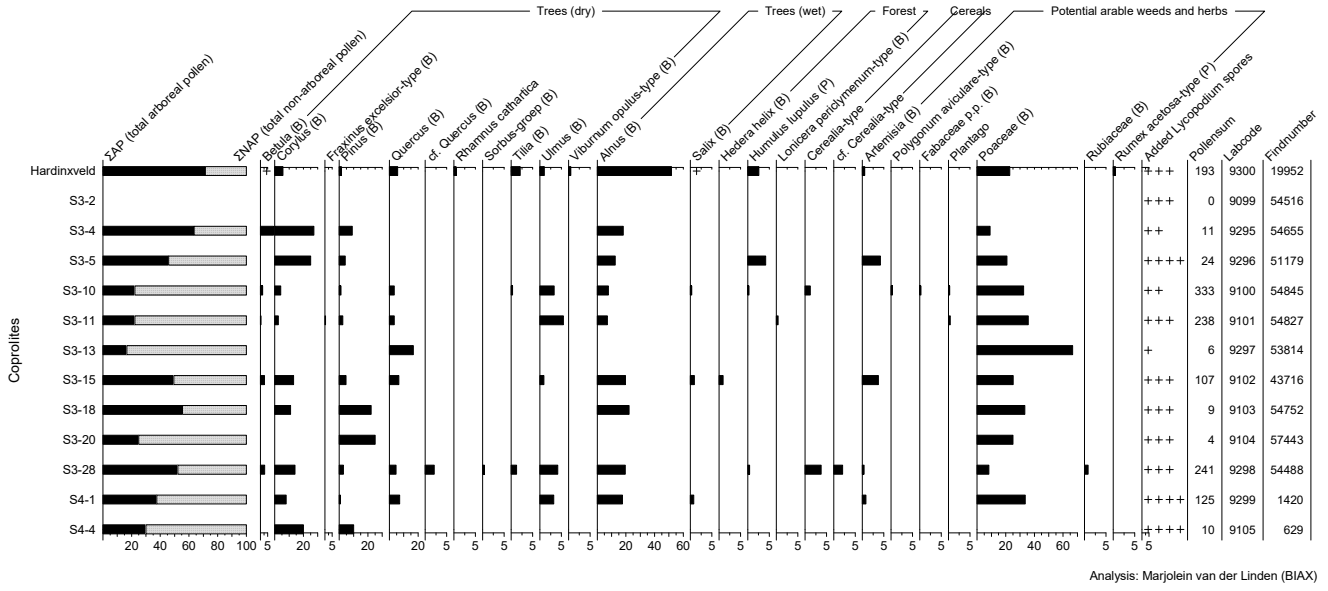


Figure 10.1 Pollendiagram of taxa found in the Swifterbant coprolites (part 1). Legend: c = charred, cf.= possible, B= pollentype according to Beug; P= pollentype according to Punt , += present.

10.3 Results

The results of the pollen analysis are summarised below. The pollen composition of the coprolites as well as the finds of other microfossils will be discussed. The pollen counts and percentages are presented in Appendices VIII and IX. The pollen types are grouped into ecological categories to aid the description and interpretation of the results of the analysis (see Appendices VIII and IX). On the slides prepared for the analysis of intestinal parasites, pollen, spores, and other microfossils were also present. These pollen and spores were counted. These counts can be found in Appendix X. All results will be discussed in this chapter. Summaries of these results can be found in Tables 10.2, 10.3 and 10.4.

The oldest sample from the Late Mesolithic-Early Neolithic Hardinxveld-Giessendam De Bruin will be discussed first, followed by the samples from the Early Neolithic Swifterbant-S3 and -S4. The pollen composition of the coprolites are presented in pollen diagrams showing the ratios between arboreal and non-arboreal pollen and the pollen taxa (Fig. 10.1 and Fig. 10.2).

10.3.1 Hardinxveld-Giessendam De Bruin

Pollen concentration

The pollen concentration in the Hardinxveld-Giessendam De Bruin coprolite (19952) is very low. A total of 193 pollen and spores were counted.

Arboreal/non-arboreal pollen

The pollen assemblage is dominated by arboreal pollen (71.5%). Most of the tree pollen originated from alder (*Alnus*, 51.8%). Oak (*Quercus*) and hazel (*Corylus*) are frequently present (each 5.7%). Pine Pine (*Pinus*), birch (*Betula*), Buckthorn (*Rhamnus cathartica*), lime (*Tilia*), elm (*Ulmus*), and Guelder-rose (*Viburnum opulus-type*) were present in the surrounding vegetation on moist to drier grounds.

The non-arboreal pollen assemblage is dominated by grasses (Poaceae, 22.8%). Some (or most) of these pollen grains may be of reed (*Phragmites*). Pollen of common sorrel-type (*Rumex acetosa-type*), goosefoot family (*Chenopodiaceae*) and common heather (*Calluna vulgaris*) represent open vegetation possibly associated with human activity on the river dune. The presence of pollen of Hop (*Humulus*) and meadowsweet (*Filipendula*), as well as spores

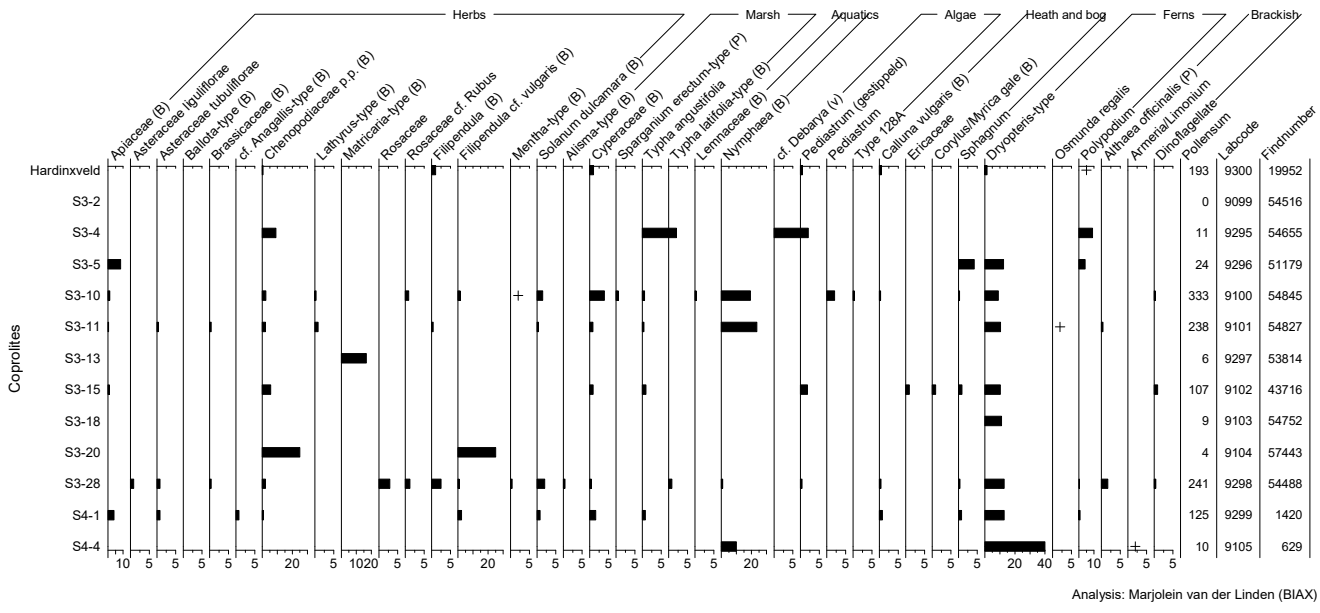


Figure 10.2 Pollendiagram of taxa found in the Swifterbant coprolites (part 2). Legend: c = charred, cf.= possible, B= pollentype according to Beug; P= pollentype according to Punt , += present.

Table 10.2 Summary of results of pollen analysis of trees, grasses, and cereals.

Sample	Find	Labcode	AP/NAP	Total pollensum	Pollensum IP	Pollen concentration (n/ml)	pollen concentration IP (n/ml)	Alnus (%)	Corylus (%)	Quercus (%)	Grassland plants (%)	Cereal pollen (%)	Other cereal remains	Producer (GC-MS)
Hardinx.	19952	BX9300	72/28	193	2	very low	97	51,8	5,7	5,7	23,3	.	.	pig
S3-2	54516	BX9099	-	0	.	extremely low	.	.	.	.	.	.	cf. epidermis (c)	pig
S3-4	54655	BX9295	64/36	11	1	extremely low	14	18,2	27,3	.	9,1	+	T. cf. dicoccum, epidermis (c)	dog/ human
S3-5	51179	BX9296	46/54	24	.	extremely low	.	12,5	25,0	.	20,8	.	.	ruminant?
S3-10	54845	BX9100	22/78	333	55	low (8906)	705	7,8	4,2	3,3	34,2	1,2	pericarp likely Hordeum	dog/ human
S3-11	54827	BX9101	22/78	238	49	low	845	7,1	2,5	3,4	37,0	.	T. cf. dicoccum, epidermis (c),	not faecal
S3-13	53814	BX9297	17/83	6	2	extremely low	27	.	.	16,7	66,7	.	cf. epidermis (c)	dog?
S3-15	43716	BX9102	50/50	107	.	low (6432)	.	19,6	13,1	6,5	25,2	.	.	pig
S3-18	54752	BX9103	56/44	9	.	extremely low	.	22,2	11,1	.	33,3	.	T. cf. dicoccum, epidermis (c)	n.d.
S3-20	57443	BX9104	25/75	4	.	extremely low	.	.	.	.	25,0	.	pericarp Triticum cf. dicoccum	human
S3-28	54488	BX9298	52/48	241	13	very low	259	19,5	14,1	4,6	9,1	5,8	T. cf. dicoccum, epidermis (c)	human/ ruminant
S4-1	1420	BX9299	38/62	125	9	very low	82	17,6	8,0	7,2	34,4	+	T. cf. dicoccum, epidermis (c)	n.d.
S4-4	629	BX9105	30/70	10	3	extremely low	19	.	20,0	.	20,0	.	.	n.d.

Legend: c = charred, n.d.= no data, += present

of ferns of the buckler/male fern-type (*Dryopteris*-type) and Polypody (*Polypodium*) indicates open spaces in the forest and wetland areas near the Hardinxveld-Giessendam De Bruin site.

Fungal remains

Several spores of dung fungus (*Chaetomium*) are present (5.2%), indicating the presence of dung on the site. This may mean that exposed (decomposing) faeces were eaten (coprophagia) or that these dung fungi grew on surface of the faeces before or during the early mineralisation stage. This may be an indication that the faeces were exposed for some time before they were buried in sediment. Other fungal spores are probably of rust fungi, possibly of *Uromyces* and *Puccinia*, which infect plant leaf tissue. *Gelasinospora* is found on charred plant remains.

Other plant tissues and microfossils

Many charcoal fragments and charred plant remains were found, some of which could be identified as charred epidermis of grasses (Poaceae and *Phragmites*) and/or sedge family (Cyperaceae). Charred (woody) rings from vascular plant tissue were also noted. One seed testa fragment of the aquatic white water-lily (*Nymphaea alba*) was present, as were fragments of leaf epidermis as well as tissues of waterlogged plants and charred plant tissues of which some could be identified as the epidermis of reed; Fig. 10.3). Furthermore, many remains of marine foraminifera were observed in the intestinal parasite slides. In addition, a curled hair of sheep (fine wool) was found (Fig. 10.4).

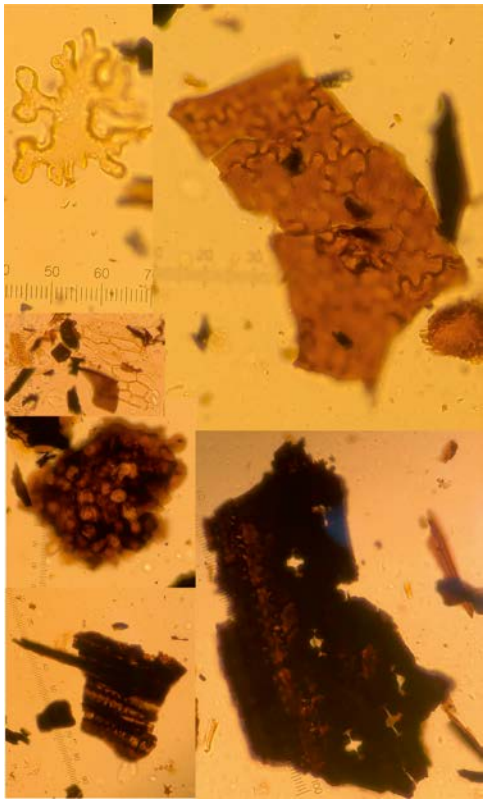


Figure 10.3 Top left: seed testa fragment of *Nymphaea alba*, and other waterlogged and charred plant tissues in the Hardinxveld-Giessendam De Bruin coprolite (19952). (scale bar: 10 stripes = 24.5 µm).

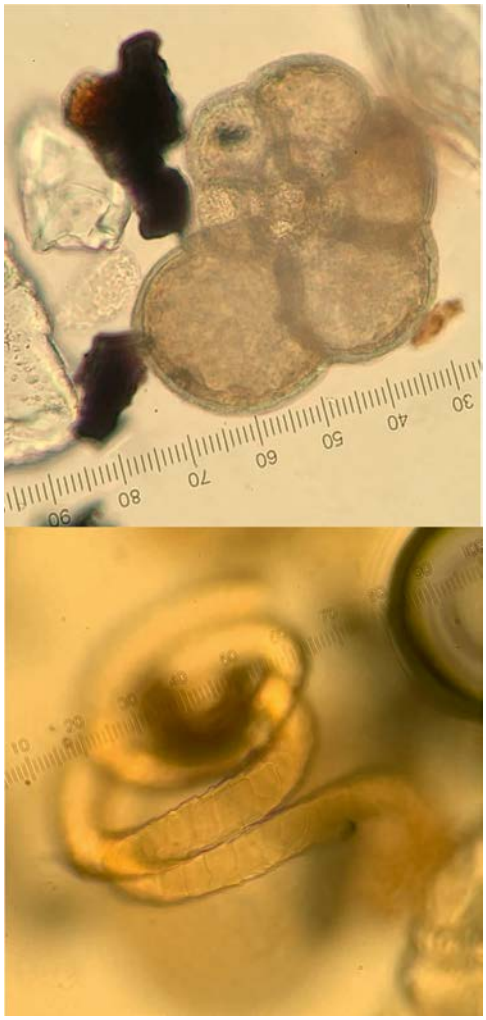


Figure 10.4 Foraminifera (top) and a curled hair, probably fine wool (bottom) on the Hardinxveld-Giessendam De Bruin parasite slide (scale bar: 10 stripes = 24.5 µm).

10.3.2 Swifterbant-S3 and -S4

Pollen concentration

The pollen concentration in the S3 and S4 coprolites ranged from low (8906 grains/ml in S3-10) to extremely low (no pollen observed in S3-2). In five coprolites, a pollen sum of over 100 pollen grains could be reached (S3-10, S3-11, S3-15, S3-28, and S4-1). The total amount of pollen on the intestinal parasite slides was also the highest in coprolites S3-10 and S3-11. Though not exactly the same pollen types are present, the general assemblage, as well as the pollen percentages of S3-10 and S3-11, are remarkably similar.

Arboreal/non-arboreal pollen

In the S3 and S4 coprolites with more than 100 pollen grains, the arboreal pollen percentages ranged between 22% and 52% in the coprolites from site S3.[178] The lowest arboreal percentages were found in S3-10 and S3-11. The pollen assemblages of these coprolites are dominated by non-arboreal pollen (78%) which would imply an open environment. It should be noted that water-lily (*Nymphaea*) pollen forms an abnormally large proportion of the pollen assemblage (19-23%) of both of these coprolites, which probably does not reflect the natural vegetation composition.[179] If the ratio arboreal/nonarboreal pollen is corrected (by excluding *Nymphaea* from the pollen sum), it would fall within the range that indicates an open forest to forest edge environment.

The arboreal pollen percentages (38% and 30%) from the two coprolites from the S4 site are a bit lower than those from the S3 site.

Alder (*Alnus*) is dominant in most of the coprolites S3 and S4. In some coprolites, S3-4 and S4-4, hazel (*Corylus*) is dominant. Hazel is a commonly accepted food plant in prehistory.[180] Oak (*Quercus*) and birch (*Betula*) pollen also predominate. In all of the coprolites more pollen from trees from relatively dry soils than from trees from wet soils are present. It should be noted here that some species of birch (*Betula*) and oak (*Quercus*) can also grow on relatively wet soils. Pollen from pine (*Pinus*) is present with relatively high percentages in almost all of the coprolites. In coprolites from S3-10, S3-11, S3-15,

178 In all of the coprolites the arboreal pollen percentages range between 17% and 64%.

179 In addition, 28 and 38 pollen grains of *Nymphaea* were counted on the intestinal parasite slides of S3-10 and S3-11, respectively.

180 Kubiak-Martens 1999; Out 2009.

Table 10.3 Summary of results of pollen analysis of herbs.

Sample	Find	Labcode	Selection of herbs	Ferns	Animal remains	Plant tissue (uncharred)	Producer (GC-MS)
Hardinxveld	19952	BX9300	Artemisia, Chenopodiaceae, Filipendula	Dryopteris-type, Polypodium	Fine wool (sheep)	Nymphaea alba, seed testa fragment, rosette-shaped plant tissue, spongy tissue/ pericarp, leaf epidermis	pig
S3-2	54516	BX9099	-		.	.	pig
S3-4	54655	BX9295	Chenopodiaceae, Typha angustifolia	Polypodium	.	.	dog/human
S3-5	51179	BX9296	Artemisia, Humulus	Dryopteris-type, Polypodium	.	rosette-shaped plant tissue, spongy tissue/pericarp	ruminant?
S3-10	54845	BX9100	Polygonum aviculare-type, Lathyrus-type, cf. Rubus, Filipendula cf. vulgaris, Mentha-type, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Nymphaea	Dryopteris-type	Barbule, perching birds/waders	Nymphaea alba, seed testa fragment, rosette-shaped plant tissue	dog/human
S3-11	54827	BX9101	Lathyrus-type, Filipendula, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Althaea officinalis, Nymphaea	Dryopteris-type, Osmunda regalis	Hair, likely red deer	Nymphaea alba, seed testa fragment, rosette-shaped plant tissue, spongy tissue/ pericarp, leaf epidermis	not faecal
S3-13	53814	BX9297	Poaceae, Matricaria-type		Fine wool (sheep)	spongy tissue/pericarp	dog?
S3-15	43716	BX9102	Artemisia, Typha angustifolia, Chenopodiaceae	Dryopteris-type	Fine wool (sheep)	.	pig
S3-18	54752	BX9103	Alnus, Poacaea	Dryopteris-type	.	spongy tissue/pericarp	n.d.
S3-20	57443	BX9104	Filipendula cf. vulgaris, Chenopodiaceae	.	.	rosette-shaped plant tissue, bulb epidermis (cf. Allium)	human
S3-28	54488	BX9298	Artemisia, Rosaceae cf. Rubus, Filipendula cf. vulgaris, Mentha-type, Solanum dulcamara, Typha latifolia, Chenopodiaceae, Althaea officinalis, Nymphaea	Dryopteris-type, Polypodium		rosette-shaped plant tissue, spongy tissue/pericarp	human/ruminant
S4-1	1420	BX9299	Artemisia, Filipendula cf. vulgaris, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Althaea officinalis	Dryopteris-type, Polypodium		Nymphaea alba, seed testa fragment. rosette-shaped plant tissue, Monocot epidermis	n.d.
S4-4	629	BX9105	Poacaea, Lemnaceae, Armeria/ Limonium, Nymphaea	Dryopteris-type, Polypodium		spongy tissue/periderm, Monocot epidermis	n.d.

Legend: cf.= possible, n.d.= no data.

S3-28 and S4-1, pollen from lime (*Tilia*) and/or elm (*Ulmus*) is present. *Pinus*, *Tilia*, and *Ulmus* were probably growing on the higher parts in the landscape. The presence of the pollen of the mountain-ash-type (*Sorbus*-type) in S3-28 implies that certain Rose family (Rosaceae) trees (e.g. mountain ash (*Sorbus aucuparia*), hawthorn (*Crataegus*) and apple (*Malus*) were growing near the site (or were consumed). The high percentages of *Alnus* in all of the coprolites reflect that alder trees were growing on the wet soils near the settlement, probably in the back-swamp. Also, willow (*Salix*) carr and birch carr were probably present near the settlement site.

Cereal remains

Cereal pollen is present in three coprolites from S3 (S3-4, S3-10 and S3-28) and in one from S4 (S4-1). In some of the coprolites other remains of cereals were found. In S3-4, S3-11, S3-18, S3-20, S3-28, and S4-1, charred epidermis of likely emmer (*Triticum cf. dicoccum*) could be identified (see Fig. 10.5). In S3-2, S3-13, and S4-4, possible cereal epidermis is present. In S3-10, a fragment of cereal bran was discovered which is likely barley (*Hordeum*) pericarp. In S3-20 (human coprolite) another small fragment which probably represents cereal pericarp was present. The dotting on the cell walls is characteristic for the transverse cells of *Triticum*. At Swifterbant

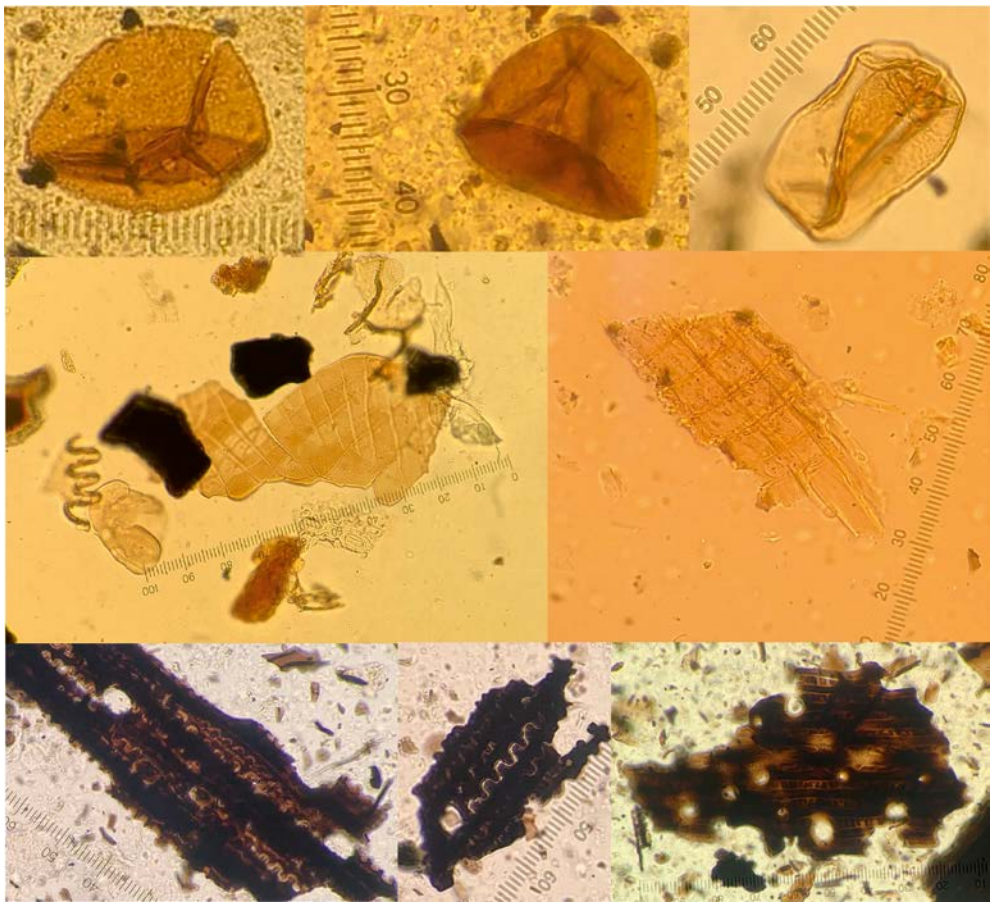


Figure 10.5 Top: cereal pollen, middle: pericarp fragments likely of barley (*Hordeum*; left) and likely emmer (*Triticum cf. dicoccum*; right), bottom left and middle: charred chaff epidermis of emmer and bottom right: fine chaff (husk) of emmer from S3 coprolites (scale bar: 10 stripes = 24.5 µm).

that would likely have been emmer (*T. dicoccum*). In the coprolites from S3-2, S3-5 and S3-15, no cereal remains were noted during the pollen analysis.

Herbaceous pollen assemblage

The non-arboreal pollen assemblages of almost all of the coprolites from S3 and S4 are dominated by grassland plants (mostly Poaceae including *Phragmites*). Only in S3-28 are grasses less dominant, but a large variety of other herbs ranging from marsh and riparian vegetation to ruderals and potential arable weeds is present. In comparison to other coprolites, a rather large percentage of cereal pollen (5.8%) is present in S3-28. Furthermore, the pollen of mugwort (*Artemisia*, a ruderal) was found, as well as pollen of the weeds composite family ray florets (Asteraceae liguliflorae), composite family disk florets (Asteraceae tubuliflorae), mustard family (Brassicaceae), and goosefoote family (Chenopodiaceae), of which some species may be regarded as potential arable weeds and ruderals.

In other coprolites, the pollen of potential arable weeds and ruderals was also found. In the coprolite from S4-1, one pollen grain, which probably belongs to the pimpernel-type (*Anagallis*-type), is present. [181] This pollen type can be seen as a potential arable weed (e.g. scarlet pimpernel, *Anagallis arvensis*), although other species within this type grow in natural vegetation (e.g. tuffed loosestrife, *Lysimachia thyrsiflora,* in alder carr).[182] A pollen grain of knotgrass (*Polygonum aviculare*) is present in S3-10. *Polygonum aviculare* is regarded as a potential arable weed.[183] Van Zeist and Palfenier-Vegter have already shown that Swifterbant S3 is the earliest site in Dutch history where this species was present in the archaeobotanical

[181] The identification was hampered by a large amount of small inorganic particles in the pollen slides of S4-1.
[182] Out 2009; Beug 2004, 342-343.
[183] Out 2009.

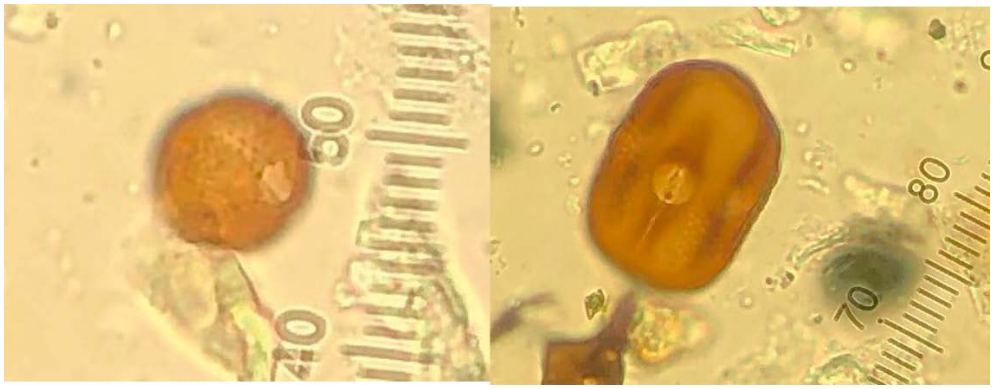


Figure 10.6 Left: *Filipendula* cf. *vulgaris* pollen and right: *Lathyrus*-type pollen (scale bar: 10 stripes = 24.5 µm).

composition.[184] Leaf remains of knotgrass were also found in the Swifterbant coprolites (see Chapter 8).

In coprolites S3-10 and S3-11, a large variety of herbaceous pollen taxa was documented. In these two coprolites, extremely high pollen percentages from *Nymphaea* (19% and 23%, respectively) were found. The *Nymphaea* pollen grains may have entered the coprolite material via food and/or drinking water. White water-lily (*Nymphaea alba*) seed pots (capsules) and seeds are edible (see also section Other plant tissues and Chapter 8).[185] The seeds are very starchy.[186] White water-lily was most probably growing in a body of fresh water near the settlement and was collected there. Other pollen types from these coprolites point to a wet environment as well. The pollen assemblage is dominated by grasses (including reed) and a large variety of herbal pollen types is present, including marsh and riparian vegetation (Branched bur-reed, *Sparganium erectum*-type; lesser bulrush, *Typha angustifolia;* and bulrush, *T. latifolia*). In addition, dropwort (*Filipendula* cf. *vulgaris*), mint (*Mentha*), and bittersweet (*Solanum dulcamara*) were growing on the somewhat drier parts of the banks of the creek system. Some of the pollen grains seem to be of dropwort (*Filipendula vulgaris*) rather than meadowsweet (*F. ulmaria*) (Fig. 10.6). Both species grow along grasslands with fluctuating water levels, meadowsweet in wet woodland, damp meadows, swamps, and tall-herb fen, and dropwort on more loamy, calcareous soils in calcareous grasslands and rough pasture. The Everlasting-pea-type (*Lathyrus*-type) pollen found in coprolites S3-10 and S3-11 may originate from slenderstem peavine (*Lathyrus palustris*). *Lathyrus palustris* grows in base-rich fens, fen-meadows, and marshy environments along rivers (e.g. with *Filipendula*).[187] Edible plant parts are present in both taxa, *Lathyrus* (possibly the seeds) and *F. ulmaria* and *F. vulgaris* (young leaves and tubers). Charred tubers of *F. vulgaris* have been found in archaeobotanical studies in Finnish Stone age sites.[188] *Filipendula* also has a medicinal purpose.

In coprolites S3-10 and S3-28, pollen grains of likely bramble (Rosaceae cf. *Rubus*) are present. Fruits of bramble (*Rubus fruticosus*) are edible and known to be one of the main collected foods of the Mesolithic and Neolithic.[189] It is likely that *Rubus fruticosus* was growing near the site.

In coprolite 3-28, a total of six pollen grains of marsh mallow (*Althaea officinalis*) are present (Fig. 10.7). Also in coprolite S3-11, one pollen grain of *Althaea officinalis* was found. *Althaea officinalis* grows in (salt) marsh environments e.g. in brackish reedlands. The presence of such a high number of *Althaea officinalis* pollen grains in one coprolite is unusual. This would imply that either *Althaea officinalis* was growing locally, or that the pollen grains were present in food or drink. The roots and leaves can be used as food. Furthermore, the flowers, leaves, and roots of *Althaea officinalis* are used in herbal medicine to treat abdominal pain.[190] It is very possible that the plant was collected or that the pollen was brought in together with plant remains from a coastal environment.

In coprolite S4-1, a pollen grain of *Armeria/ Limonium*-type was found. The pollen grains of *Armeria* and *Limonium* cannot be distinguished morphologically. Both species grow along the coast in brackish to saltwater environments. The leaves of *Limonium* are edible. The roots can also be used medicinally in the treatment of consumption with haemorrhage.[191]

184 Van Zeist & Palfenier-Vegter 1981. RADAR2012.
185 De Cleene & Lejeune 1999, 694-695; Launert 1984; Kubiak-Martens *et al.* 2015b, Brinkkemper *et al.* 1999.
186 De Cleene & Lejeune 1999, 694-695; Launert 1984; Kubiak-Martens *et al.* 2015b.
187 Weeda *et al.* 1987, 127.
188 Vanhanen & Pesonen 2015.
189 Hardy & Kubiak-Martens 2016; Bakels 2006; Out 2009.
190 Starý & Jirasék 1990, 52.
191 Moerman 2009.

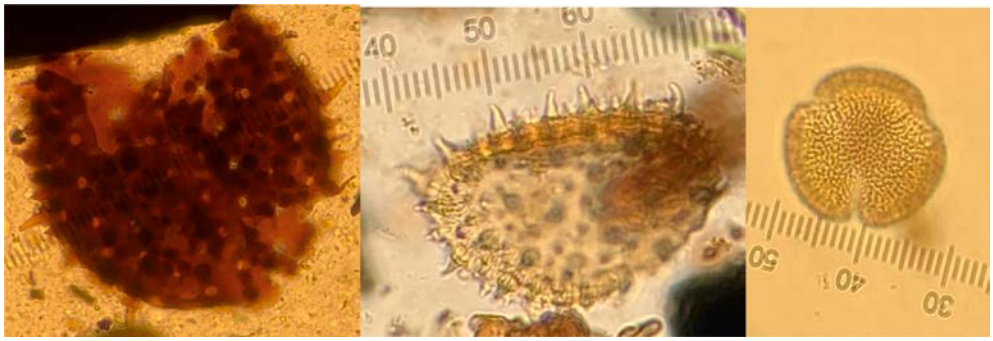


Figure 10.7 Left and middle: *Althaea officinalis* pollen and right: *Armeria/Limonium* (scale bar: 10 stripes = 24.5 µm).

In some coprolites (S3-10, S3-28 and S4-1), heather (*Calluna vulgaris*) pollen is present. *Calluna vulgaris* grows either on dry, sandy soils or in raised bog vegetation. Spores of *Sphagnum* were found in several coprolites (S3-5, S3-10, S3-15, S3-28 and S4-1).

The presence honeysuckle-type pollen (*Lonicera periclymenum*-type) in coprolite S3-28 is quite remarkable. *Lonicera periclymenum* is an insect-pollinated, woody climber found in woodland and scrubs. It prefers moist to dry, moderately basic to acidic soils, but also grows on poorly-drained base-rich clays. It can be found in most types of oak-birch forest, riparian forest, (birch-rich) alder carr, and *Sphagnum* reed land. Although the berries of *Lonicera periclymenum* are poisonous, the nectar from its flowers is edible and can be sucked out from the tubular flowers (hence the name honeysuckle). *Lonicera* is also a host plant for many insects.[192]

Table 10.4 Summary of results of other microscopic remains.

Sample	Find	Labcode	Poaceae/Cyperaceae, epidermis (c)	Cf. Phragmites, charred epidermis	Woody rings, plant vessels, charred	Charcoal, fragments	Charred plant remains	Freshwater microfossils	Brackish/marine microfossils	Dung fungi	Producer (GC-MS)
Hardinxveld	19952	BX9300	+	.	+	+	++++	+	+	+	pig
S3-2	54516	BX9099	+++	.	.	++++	++++	.	n.d.	.	pig
S3-4	54655	BX9295	+	.	+	++	++++	+	+	.	dog/human
S3-5	51179	BX9296	+	.	.	+	++	.	n.d.	.	ruminant?
S3-10	54845	BX9100	+++	.	.	.	.	+	+	+	dog/human
S3-11	54827	BX9101	++	+	+	++	+++	+	+	.	not faecal
S3-13	53814	BX9297	++	+	+	+	++++	.	+	.	dog?
S3-15	43716	BX9102	+++	+	.	++	+++	+	+	+	pig
S3-18	54752	BX9103	++	.	.	++	++++	.	n.d.	.	n.d.
S3-20	57443	BX9104	++	.	+	++	++++	.	n.d.	.	human
S3-28	54488	BX9298	+	.	+	+	+++	+	+	.	human/ ruminant
S4-1	1420	BX9299	+	.	+	+	+	+	+	.	n.d.
S4-4	629	BX9105	+	+	+	+	++++	.	+	.	n.d.

Legend: c = charred, n.d.= no data, += present, ++= numerous, +++= abundant, ++++= extremely abundant.

[192] Weeda *et al.* 1988, 272-275.

Perhaps when honey (or an insect) was consumed, pollen grains may have entered the coprolites. Also, the juice from the berries of honeysuckle is used as a muscle relaxant and laxative in herbal medicine.[193]

Fern spores

In all of the coprolites (except for S3-2 and S3-20, in which no pollen to hardly any pollen was present) many spores of various ferns were found. Most of the spores are from the buckler/male fern-type (*Dryopteris*-type) which represents ferns that grow in open spots in forested areas, in fen or fen carr or on shady river banks. Crested wood fen (*Dryopteris cristata*) and marsh fern (*Thelypteris palustris*), for example, grow in alder carr.[194] Royal fern (*Osmunda regalis*) grows in wet, neutral to acidic substrates in fen carr (e.g. birch-rich alder carr) and on riverbanks.[195] Polypody (*Polypodium vulgare*) is most commonly found in dune areas, but also in open forests. The fern also occurs as an epiphyte on oak and other deciduous trees (in clay areas, on willows).[196] The rhizomes of *Dryopteris* and *Polypodium* are edible and have a bittersweet taste. These rhizomes are also used in herbal medicine for their anthelmintic properties (against parasitic worms).[197] An infusion of the rhizomes of *Osmunda regalis* has diuretic properties (increases the production of urine).[198]

Other plant tissues

In addition to pollen, many seed testa fragments of *Nymphaea alba* are present in coprolites S3-10 and S3-11 (Fig. 10.8). In coprolite S3-28, some seed testa fragments of *Nymphaea alba* are also present. The seeds of water-lily were also detected in the micro CT-scans and SEM-analysis (see Chapters 6 and 8). The large amounts of pollen of *Nymphaea* and fragments of seed testa of *Nymphaea alba* do not point to natural vegetation composition. It is therefore likely that white water-lily was consumed. The seed pods (capsules), seeds, and roots of this species are edible. Other archaeobotanical studies from Neolithic sites have already proposed the consumption of Nymphaeaceae.[199] The plants were collected from nearby waters. The seed pods can be cooked and eaten. The seeds are very starchy (40-47%) and can be ground into flour. [200] Furthermore, *N. alba* was used in Indian herbal medicine. In herbal medicine in Northwest Europe, treatments with flowers and rhizomes have a calming effect and stimulate the relief of spasms.[201] Recent studies reported the antioxidant, anti-inflammatory, and hepatoprotective effects of *N. alba* flowers.[202] It has also been reported as a remedy for dysentery.[203] Perhaps consumption of the *N. alba* seed pods eased abdominal pains due to worm burdens as well as hunger.

In coprolites S3-10 and S3-11, fragments of the epidermis are present that resembles the berry/fruit skin of *Rubus* (bramble or blackberry) and/or *Malus* (apple) (Fig. 10.8). This interpretation must be made with caution since the rosette-like feature around a cell (probably where a hair was attached) is also present in other species. Both *Rubus* and *Malus* fruits are known as part of the common Late Mesolithic and Neolithic diets. Seeds of both of these taxa

193 Chiej 1984, 181.
194 Weeda *et al.* 1985, 44-48, 93-97.
195 Weeda *et al.* 1985, 93-97.
196 Weeda *et al.* 1985, 49-51.
197 Weeda *et al.* 1985, 49-51; Van Os 1974, 95; Chiej 1984, 244; Moerman 2009, 375-376.
198 Chiej 1984, 216.
199 Kubiak-Martens *et al.* 2015; Out 2009.
200 Chiej 1984, 206; Chakravarty 1976.
201 Van Os 1974, 247.
202 Bakr *et al.* 2017.
203 Launert 1984.

Figure 10.8 Left: epidermis with rosette-like features likely of *Malus* (or *Rubus*) fruit on S3-11 parasite slides. Right: *Nymphaea* pollen (top) and fragments of *Nymphaea alba* seed testa in coprolite S3-11 (bottom) (scale bar: 10 stripes = 24.5 µm).

have been found at Swifterbant S3 and S4.[204] The CT-scan of the S3-10 coprolite revealed seeds of apple (see Chapter 6). An apple seed was also found in S3-28 with SEM-analysis (see Chapter 8). In S3-10, a large lump of sclereids is present (Fig. 10.9). Sclereids can be found in fruit parenchyma (for example in *Malus* and *Vaccinium* berries) but also in roots and leaves.[205]

Fragments of spongy tissue with thick cell walls consisting of round cells were observed (S3-5, S3-13, S3-18, S3-28 and S4-4). It is very well possible that these types of cell layers represent spongy parenchyma (from leaves) or cell layers found in the periderm of roots and tubers.[206] In the coprolite from S3-20, another type of thick-walled cell tissue is present. A large fragment of thick-walled cell tissue in which the cells have a more rectangular appearance was found. Some of the cells have a more pointy end (V-shaped end). This epidermis strongly resembles the epidermis of leek/garlic (*Allium*). Although *Allium* epidermis is known for its characteristic pointed or V-shaped cells, a study of recent epidermal tissue of ramsons (*Allium ursinum*) bulbs, showed that areas with more rectangular cells were also present (Fig. 10.10). Although the cells appear a bit smaller in the Neolithic epidermal tissue than in the recent tissue, the thickness of the cell walls matches (c. 7.5 to 8.5 µm).

Leaf fragments of peat moss (*Sphagnum*) were found during the analysis of two coprolites (S3-28 and S4-1) (Fig. 10.11). Remains of various *Sphagnum* species were also found at the S3 site by van Zeist and Palfenier-Vegter, including the raised bog species *Sphagnum imbricatum,* the bog and alder carr species *Sphagnum palustre,* and the bog species *S. papillosum*. The absence of *Calluna* seeds and other raised bog species was noted as surprising. The suggestion was made that *Sphagnum* remains were of secondary origin (from peat deposits, which had been cut into the creeks).[207] The *Sphagnum* leaves encountered in our study are definitely not of *S. imbricatum* or S. *papillosum.* These leaves are possible of *Sphagnum palustre* and may have been growing in nearby alder carr, willow carr or birch carr.

One trichome (hair) – or, possibly, a trichosclereid - is present in coprolite S3-28 (Fig. 10.12). Branched trichosclereids are found, for example, within the open tubes of the leaf petiole (stalk) of *Nymphaea alba*. However, many plants have leaves or stems with trichomes.

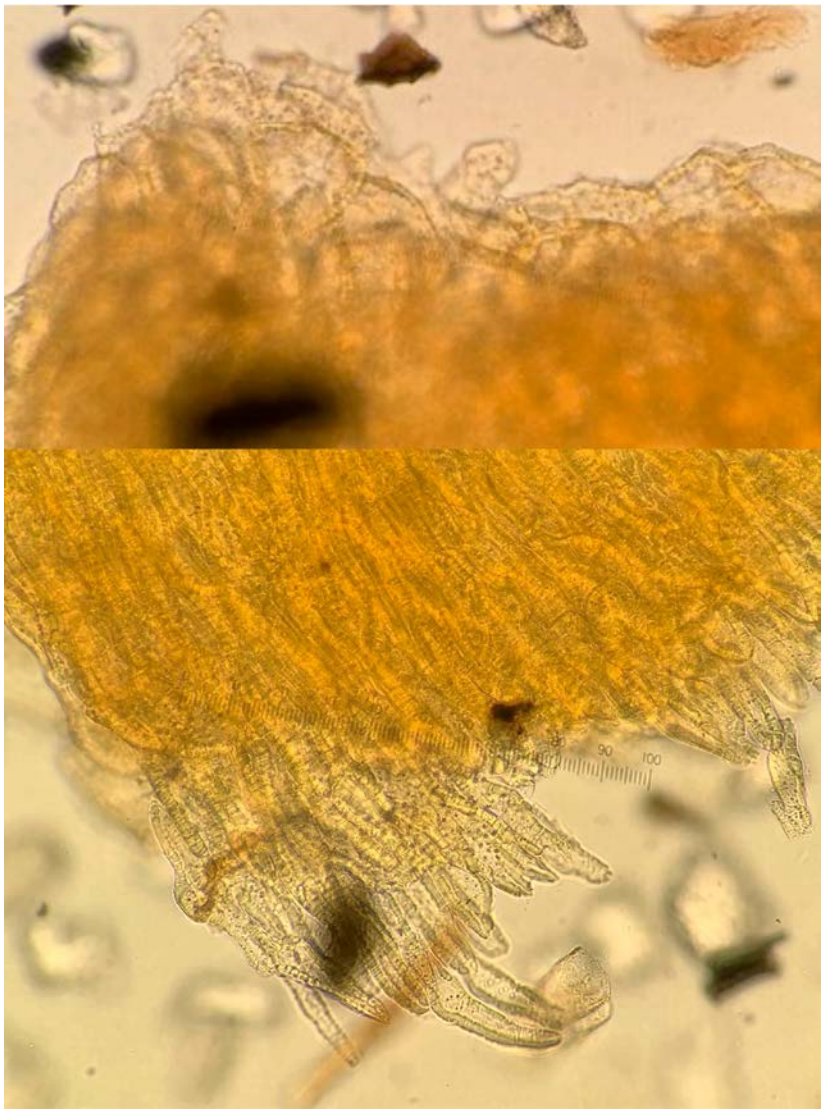


Figure 10.9 Close-ups of a large lump of sclereid tissue in the parenchyma on the S3-10 parasite slide. Both rounded (above) and elongated sclereid (below) are present in the same piece. (scale bar: 10 stripes = 24.5 µm.

Charcoal particles and charred epidermal remains (e.g. graminoid epidermis) or parenchyma cells were observed in almost all of the coprolites. Some of the epidermis fragments could be identified as *Phragmites*. It is possible that young shoots of *Phragmites* were consumed. The charred microscopic particles may also represent inhaled ash from a fire within the house, for example. Charred elements of vascular tissue (xylem vessels) were found in several coprolites (Fig. 10.13). Several types of phytoliths were also observed (see Chapter 7).

[204] At the S3 site, wood of *Malus* is present (Van Zeist & Palfenier-Vegter 1981). At the S4 site, both *Rubus fruticosus* and *Malus* are present in the archaeobotanical study (Schepers & Bottema-Mac Gillavry 2020).
[205] See examples in Hohman 2007, 259-360.
[206] Hohmann 2007, 69, 217.

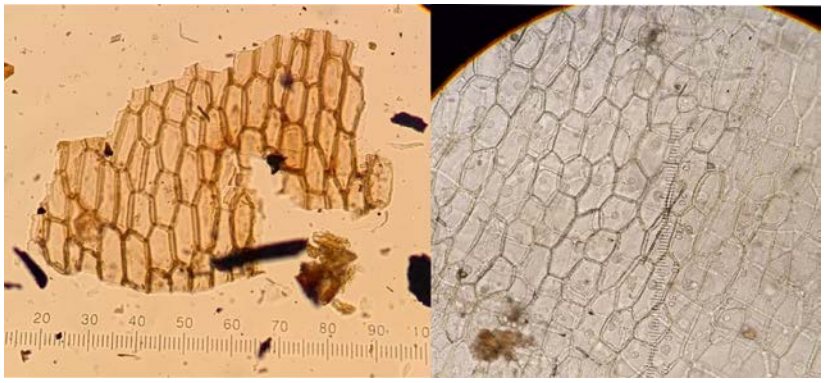


Figure 10.10 Left: thick-walled cell tissue from coprolite S3-20; right: bulb epidermis from *Allium ursinum* (scale bar: 10 stripes = 50 µm).

Figure 10.11 *Sphagnum* leaf fragment from S4-1 (scale bar: 10 stripes = 24 ,5 µm).

Figure 10.12 Left: Trichome found in S3-28; right: trichome of *Nymphaeaceae* leaf material on pollen slide of collection material.

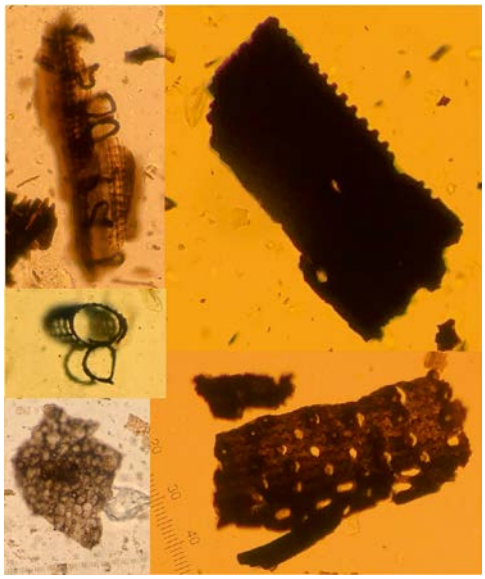


Figure 10.13 Charred plant cell tissue e.g. vascular tissue (top left and middle left), unknown parenchyma tissue (bottom left), graminoid tissue (top right), *Phragmites* epidermis (bottom right) on S3-28 parasite slides (scale bar: 10 stripes = 24.5 µm).

Animal remains

In two coprolites (S3-13 and S3-15), hairs of sheep (fine wool) were found. Furthermore, in S3-11, a tiny fragment of an animal hair was present. The hair fragment probably originated from likely red deer (*Cervus elaphus*) or possibly a goat (*Capra*)(Fig. 10.14).[208] It is certainly not from another species of cattle, pig, sheep, human, dog, or cat, or wild animals otter and beaver. The GC-MS analysis suggests that the coprolites in which hairs were found were produced by carnivores or pigs (one had no sufficient data).[209] Hairs can enter faeces in multiple ways. Either when the producer has been licking its fur, by consumption of animal remains, or via inhalation of small fragments. Since the hairs were not from the same species as the proposed producers the hairs were probably not from the producer fur. These tiny hair fragments were possibly consumed with meat. Another explanation may be that these tiny hair fragments were inhaled when an animal skin or wool was processed.

A barbule (the smallest part of a bird feather) is present in coprolite S3-10. Due to the presence of pigmented, oval-shaped nodes in the barbule, it could be identified as coming from a perching bird or wader (Passeriformes or Charadriiformes).[210] Another unidentified microscopic object with a similar shape found in the same coprolite may be a charred barbule (Fig. 10.15).

Several, chitinous hooklets, some small and some large, were found which are probably of unidentified animal origin (Fig. 10.16). Various insects and larva of insects have hooklets on their body. Although some tapeworms (e.g. pork tapeworm, *Taenia solium*) have small and large hooklets on the rostellum, the hooklets could not be identified as such. On some pollen slides, eggs of intestinal parasites were found. The eggs of intestinal parasites were further studied and are discussed in Chapter 11.

207 Van Zeist & Palfenier-Vegter 1981, 117.

208 The fragment also resembled the medulla (inner part) of the hair from goat but the scalloped features which are characteristic for goat are not observed (Brunner & Coman 2009). Instead the thick walls and broad (unscalloped) scales are present which point to red deer (Teerink 1991, 213; De Marinis & Asprea 2006).

209 One was not confirmed as faecal by the lipid analysis.

Figure 10.14 Hair fragment from S3-11, likely red deer (scale bar: 10 stripes = 24.5 µm).

Fungal remains

Several spores of dung fungi (*Chaetomium*, *Cercophora*, and *Sordaria*) are present in coprolite S3-10. This may mean that exposed (decomposing) faeces were eaten or that these dung fungi grew on the surface of the faeces themselves for some time before they were buried in sediment. In almost all of the coprolites, fungal spores of the Basidiomyceta family were found. Most of these spores are probably of rust fungi, possibly of *Uromyces* and *Puccinia*, which infect plant leaf tissue. In coprolite S3-28, many basidiospores (cf. HdV-256) were found. This type probably belongs to the Ustilaginales and may represent a parasite of cultivated plants.[211] *Gelasinospora* (S4-4) can be found on charred plant remains.

Fresh and saltwater microfossils

In all of the coprolites of which slides were prepared for intestinal parasites analyses, several marine diatoms were observed. Some diatoms could be identified: *Actinoptychus senarius*, *Aulacodiscus argus*, cf. *Actinocyclus*, and *Podosira stelliger*.[212] Freshwater indicators are also present, e.g. diatoms, green algae *Pediastrum*, and spicules of spongae. The presence of marine diatoms indicates ingestion of marine microfossils via drinking water or food. Possibly, the drinking water was slightly brackish or (older) marine microfossils from the clay bedding in the creek were diluted in the fresh water. However, the diatom analysis of S4 has shown that freshwater diatoms were pristine, whereas the marine ones were mostly broken which would indicate a reworking of marine microfossils in fresh water.[213]

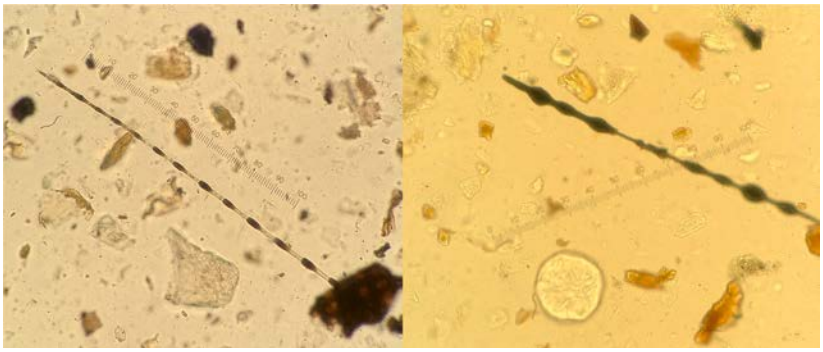


Figure 10.15 Left: Barbule of perching bird or wader, right: charred object most likely a charred barbule. Both objects were found in S3-10 (scale bar: 10 stripes = 24.5 µm).

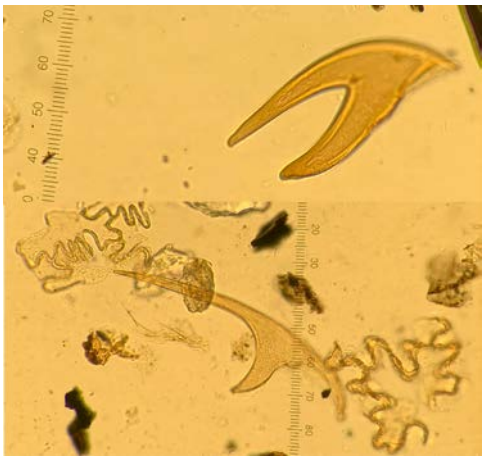


Figure 10.16 Top: small hooklet (c. 65 µm); bottom: large hooklet (c. 150 µm) on S3-10 parasite slide (scale bar: 10 stripes = 24.5 µm). A wiggly-shaped *Nympheae* seed testa can be seen.

10.4 Discussion

10.4.1 Presence and preservation of pollen

Pollen was present in almost all of the coprolites. Only in coprolite S3-2 was no pollen found. In this coprolite, many charcoal fragments and charred plant remains were present. Perhaps the preservation of organic remains was poor and only charred remains were preserved in the coprolite. In seven other coprolites, pollen was hardly present (less than

210 Identification with the help of Kees Roselaar (bird identification expert at Naturalis Biodiversity Centre; retired).
211 Willemsen, Van het Veer & Van Geel 1996.
212 G. Verweij (Bureau Waardenburg) was consulted for the identifications of the diatoms.
213 Schepers & Woltinge 2020.

25 grains per sample). Both charred and uncharred organic remains were present in these coprolites (S3-4, S3-5, S3-13, S3-18, S3-20 and S4-4), although in most cases only the charred remains were identifiable. The pollen grains that were present, however, were well preserved. Therefore, it can be concluded that these coprolites are poor in pollen.

Coprolites S3-10, S3-11, S3-15, S3-28 and S4-1 had the highest pollen concentrations. Pollen sums ranging between 125 and 333 pollen grains per coprolite were reached. The pollen data from these coprolites will be used in the environmental reconstruction.

Some coprolites are poor in the quantity of pollen, but the preservation of the pollen is fine. The CT-scan showed that almost all coprolites had desiccation cracks, e.g. S3-11 and S4-1 (Chapter 6). At Hardinxveld-Giessendam De Bruin, and most certainly at Swifterbant, the conditions for early mineralisation must have been favourable (see Chapter 1). At both sites, a very wet environment in which clay was deposited (occasionally marine, calcareous) was present.[214] The combination with the presence of (fish) bone remains (see Chapter 7) probably promoted the mineralisation of the faeces.

10.4.2 Seasonality

Although different plant species flower during different months of the year, it is difficult to assign a specific period or seasonality to the formation and deposition of each of the coprolites. There isn't always a clear overlap in the period of pollen dispersal of the taxa present in each coprolite. For example, coprolite S3-15 contains pollen of ivy (*Hedera helix*, which flowers from September to December), hazel (*Corylus*, January-March), alder (*Alnus,* February-March), grasses (mostly summer), lesser bulrush (*Typha angustifolia*, July-August), and mugwort (*Artemisia*, July-October). It is tempting to argue that the coprolites poor in pollen were produced in winter when only a few plants flower and pollen deposition is limited. However, all of the coprolites contain pollen of plants flowering in several seasons, hampering the assignment of seasonality. This is in agreement with the coprolite study at Hardinxveld-Giessendam De Bruin.[215]

10.4.3 Environmental reconstruction

The pollen data from coprolites with more than 100 pollen grains in the pollen sum are used to give a general impression of the vegetation and environment around the settlement sites of Hardinxveld-Giessendam De Bruin and Swifterbant-S3 and -S4 (see Fig. 10.1). The pollen data from coprolites are less suitable for a detailed vegetation reconstruction since pollen enters the human body (and, eventually, the faeces) by inhalation, food, and drink (see section 10.2.3).

Hardinxveld-Giessendam De Bruin (19952)
The highest percentage of arboreal pollen was found in the coprolite from Hardinxveld-Giessendam De Bruin 19952 (71.5%). Near the site, in the wetter areas, there was alder swamp forest. On the drier soils, the mixed oak forest was present. On the forest edges and in open places where sufficient light penetrated, hazel, common buckthorn, and guelder rose blossomed. The herbaceous vegetation mostly consisted of grassland, part of which was probably reed land. The occurrence of hop suggests the presence of a more open wetland forest vegetation on the river dune.[216] The vegetation composition reconstructed from the coprolite pollen spectrum is in agreement with the vegetation reconstruction from natural deposits from Hardinxveld-Giessendam De Bruin.[217] In the coprolite, a relatively small component of the pollen originated from wetland herbs (*Filipendula* and Cyperaceae), although the pollen spectrum of the natural deposits showed a much larger variety of wetland herbs. The composition of the pollen spectrum resembled that of the three coprolites from Hardinxveld-Giessendam De Bruin in which high *Alnus*-percentages and low percentages of wetland herbs were found.[218] Interestingly, in this study, the hairs present in the Hardinxveld-Giessendam De Bruin coprolite could be identified as fine wool.

Swifterbant-S3 and -S4
The arboreal pollen percentages in the Swifterbant coprolites are lower than those in the Hardinxveld-Giessendam De Bruin coprolite 19552. The Swifterbant arboreal percentages

214 Schepers & Woltinge 2020.
215 Bakels, Van Beurden & Vernimmen 2001.
216 Bakels, Van Beurden & Vernimmen 2001.
217 Compare with Bakels, Van Beurden & Vernimmen 2001.
218 In fact, one of these coprolites has the same find number (19952) and was already studied by Bakels, Van Beurden & Vernimmen 2001.

generally suggest the presence of an open forest and/or a settlement location near the edge of a forest. Alder carr was present near the settlement in the back swamp. Along the levees of the creek, the marsh vegetation consisted of grassland (possibly including reed), bulrush species, and wetland herbs such as *Filipendula* and *Lathyrus*.

Acorns of oak were absent at S3. At S4 only one charred acorn was found. This led to the assumption that the oak forest must have been further away on the higher dunes.[219] In some, but not all, of the coprolites, *Quercus* pollen is present, but always in small quantities. The *Quercus* percentages in the coprolites of our study are much lower than in the natural deposit study by Casparie *et al*.[220] It is, therefore, very well possible that near the Swifterbant settlement sites S3 and S4, situated on the relatively wet clayey levees, hardly any oak was present or that acorns were hardly consumed.

In the settlement area, upland herbs, ruderals, and other anthropogenic indicators such as potential arable weeds would have grown, represented in the coprolites by the pollen of Asteraceae, Chenopodiaceae, Apiaceae, Fabaceae (legume family), Poaceae, Rubiaceae (madder family), *Artemisia,* and *Polygonum aviculare*. Most of these species/families (and others) were also observed in the earlier archaeobotanical studies of S3 and S4.[221]

The presence of cereal pollen implies that cereals were consumed - and possibly cultivated - on the site. At S4, a cultivated field layer was discovered, which implies the cultivation of crops.[222] In the cultivation layer on top of the cultivated field layer, the pollen of *Allium* was recorded.[223] It was suggested that *Allium* was grown locally on the site. In the Swifterbant coprolite S3-20 (human coprolite), epidermis tissue, possibly from the bulb of *Allium,* was found. It is therefore very well possible that *Allium* bulbs from a wild onion or garlic were collected and consumed at the Swifterbant settlement. The use of wild onion or garlic was earlier indicated in other Neolithic sites in the Netherlands. Parenchyma remains of charred *Allium* bulbs were found at two Middle Neolithic sites: Schipluiden-Harnaschpolder and Ypenburg.[224] *Allium* pollen was not observed in our study nor in the coprolites of Schipluiden-Harnaschpolder.[225]

Evidence for *Allium* use (possible *Allium ursinum*) comes also from the Neolithic lakeshore settlements in Switzerland, where often large amounts of *Allium* pollen were recorded from organic layers.[226] In one case also *Allium* pollen was found in pot content (food crust)[227] suggesting that *Allium* plant would have been used as a green vegetable/root vegetable, possible to flavour other food. Charred bulbs of ramsons (*Allium* cf. *ursinum*) are also known from the Late Mesolithic site at Halsskov in Denmark, where charred bulbs and numerous bulb parenchyma remains were found in features interpreted as cooking pits.[228]

Although the seeds of marsh mallow (*Althaea officinalis*) and Thrift/Sea lavender (*Armeria/Limonium*) were not observed in the archaeobotanical studies of S3 and S4, the pollen of these more coastal species was present in the coprolites.[229] Marine diatoms were also observed in the Swifterbant coprolites. These finds may imply that the environment near the settlement site was (occasionally) brackish. In that case, *Althaea officinalis* could have been growing near the settlement site. However, the marine diatoms probably represent reworked material, implying local fresh water conditions. If marsh mallow was not growing locally, the flowers or plant parts must have been brought to the settlement (probably intentionally) from the coastal region. The pollen could have entered the coprolite through a process other than inhalation, probably food or drink. The oldest finds of *Althaea officinalis* in the Netherlands are of seeds from Groningen-Westerhaven (6000–3700 cal BC) and Schipluiden-Harnaschpolder (3630-3380 cal BC).[230] Pollen of *Althaea officinalis* (or Malvaceae) was not found in the coprolites of Schipluiden-Harnaschpolder. *Malva*-type pollen was found in the pollen studies of the natural deposits of Schipluiden-Harnaschpolder, where it was concluded that it was partly of *Althaea officinalis*. No other Malvaceae seeds were found in older archaeobotanical sites.[231] *Althaea officinalis* pollen in Swifterbant (4300-3400 cal BC) may therefore be the oldest found in the Netherlands.[232]

In six coprolites, *Filipendula* pollen is present (also in the Hardinxveld-Giessendam De Bruin coprolite). *Filipendula ulmaria* seeds are found in Late Mesolithic and Early Neolithic sites in Groningen-Westerhaven, Rotterdam, Hardinxveld-Giessendam Polderweg and Hardinxveld-Giessendam De Bruin, Brandwijk,

219 Schepers & Bottema-Mac Gillavry 2020.
220 Casparie *et al*. 1977.
221 Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
222 Schepers & Bottema-Mac Gillavry 2020; Van der Veen, 2008; Schepers 2014; Huisman & Raemaekers 2008; Huisman, Jongmans & Raemaekers 2009.
223 Van der Veen 2008.
224 Schipluiden-Harnaschpolder: Kubiak-Martens 2006; Ypenburg: Kubiak-Martens 2008.
225 Bakels 2006.
226 Heitz-Weniger 1978.
227 Hadorn 1994.
228 Kubiak-Martens 2002.
229 S3-11 (one pollen grain) and S3-28 (in total, six pollen grains).
230 Resp. Vrede 2000; Kubiak-Martens 2006.
231 RADAR2012.
232 A search for *Althaea officinalis* pollen within the years 10.000 – 3000 BC in the Neotoma pollen database only had one hit. It concerned a palynological study of a lake deposit in Italy: Lago di Massaciuccoli (data under embargo).

and Hoge Vaart-A27.[233] No *Filipendula ulmaria* seeds were found during the excavations at Swifterbant.[234] *Filipendula vulgaris* is a species that grows in grasslands on calcareous soils with fluctuating water levels throughout the year. *Filipendula vulgaris* seeds of have, to the best of our knowledge, never been identified in Dutch archaeological research, nor has its pollen been recorded from prehistoric finds.[235] The latter may be attributed to the entomophilous pollination strategy of this plant. Its pollen is dispersed via insects, i.e. Hymenoptera (such as bees and wasps), Diptera (true flies) and Lepidoptera (butterflies and moths). Entomophilous plants produce little pollen which is hardly released to the atmosphere. The fact that *Filipendula vulgaris* pollen is present in many coprolites leads to the speculation that this plant may have been collected intentionally. Therefore, the plant remains possibly entered the faeces in another way than inhalation, for example via drink, food, or medicine.

10.4.4 Diet

Hardinxveld-Giessendam De Bruin

The coprolite of Hardinxveld-Giessendam De Bruin contains no pollen of cereals. Only pollen or spores from species of which edible plant remains (fruits, seeds, leaves, or tubers) were collected are present. Examples are the hazelnuts (*Corylus*), *Humulus lupulus* (leaves, shoots and roots), *Filipendula* (leaves and tubers), *Polypodium* (tuber), and perhaps also *Phragmites* (of which the young shoots are edible). Plant tissue remains suggest that *Malus* fruits and *Nymphaea* pods and seeds were also consumed. Acorns were possibly used as animal fodder or roasted and eaten by humans.[236] The presence of charred vascular tissue (xylem elements) implies the consumption of plant leaves and/or tubers.

The presence of sheep hair (fine wool) implies that food of animal origin was also consumed or that animal products were used at Hardinxveld-Giessendam De Bruin.

Swifterbant-S3 and -S4

Evidence for the consumption of cereals is present in the Swifterbant coprolites of both the S3 and S4 sites. In S3-4, S3-10, and S3-28, cereal pollen is present. Furthermore, in S3-4, S3-10, S3-11, S3-18, S3-20 and S4-1, charred epidermis of likely emmer wheat is found on the pollen slides. In S3-11, S3-20, and possibly in S3-28 charred plant tissue, probably of cereal pericarp, was recognised. The pericarp (bran fragment) in S3-10 likely belonged to barley (*Hordeum*). The fragment in S3-20 is likely emmer (*T. dicoccum*). This recognition is strengthened by the finds of charred grains of naked barley and emmer wheat at Swifterbant S3 and S4.[237] In the coprolites of Schipluiden-Harnaschpolder, pollen of cereals was present in one coprolite.[238]

The presence of many plant remains, both charred and waterlogged suggests the consumption of food plants. Many foods would have been collected in the nearby surrounding vegetation. Epidermal tissue of the bulb of, possibly, *Allium* suggests that it was gathered and used as food. Fruits of apple and/or bramble (*Malus* and/or *Rubus*) were possibly consumed by the producers of the faeces (these fruits were a common food in the Neolithic). Hazel trees, whose nuts were collected and eaten, also grew nearby. Many charred hazelnuts were found in the occupation layers of the Swifterbant sites S3 and S4.[239] *Lathyrus* seeds were possibly consumed. *Dryopteris* and *Polypodium* may have been collected for their edible roots. *Nymphaea* seeds and pods were collected from nearby water bodies and eaten. *Polygonum aviculare* and *Limonium* have edible leaves. The leaves and roots of *Althaea officinalis* and *Filipendula* (*vulgaris*) are also edible. In addition, some flowers and other plant parts (e.g. from *Tilia*, *Salix*, *Filipendula*, and *Althaea officinalis*) could have been used to make herbal drinks (or infusions). Honey was also possibly consumed.

In coprolite S3-10, a barbule (the hair-like structure of a bird's feather) is an indirect indication that bird meat was likely consumed. The other charred object found in this coprolite is probably a charred barbule, which may imply food preparation. Due to the presence of pigmented nodes in the barbule, it could be identified as coming from a perching bird or wader (Passeriformes or Charadriiformes).[240] At Swifterbant, mostly wild duck and great crested grebe bones were found.[241] The feather barbule was certainly not from one of these species.[242] It resembles that of, for example, little stint (*Calidris minuta*). Waders (stilts and stints, for example) find their food on the coastal plains and would probably have been captured there.

[233] RADAR2012: Vrede 2000; Bakels, Van Beurden & Vernimmen 2001; Out 2009; Visser *et al.* 2001.
[234] Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
[235] RADAR2012.
[236] Schepers 2014; Out 2009, 347.
[237] Casparie *et al.* 1977; Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
[238] Bakels 2006.
[239] Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020.
[240] Identification with the help of Kees Roselaar (bird identification expert Naturalis; retired).
[241] See Chapter 6, Zeiler 1997; and Kranenburg & Prummel 2020.
[242] Comparison with bird feather identification database (BRIS).

At Swifterbant S3 one bone fragment of a small wader was found.[243] Perching birds likely lived in a nearby forest or nearby the settlement site. Few bones of perching birds were found at S3, one bone fragment of jay (*Garrulus glandarius*) and three bones of carrion crow (*Corvus corrone*).[244] It is possible that bird feathers were used in bedding or for ornamentation and that small pieces of feathers may have been inhaled.

Hairs (fine wool) of presumably goat and sheep were present in the coprolites of Swifterbant. Meat and milk of goat and sheep were probably consumed. The hair fragments may have been inhaled from woolen garments or animal skins. On some pollen slides, intestinal parasites eggs were observed. These were further studied and are discussed in Chapter 11.

There is another means besides food and drink by which pollen may have entered the coprolites. This would have been consumption as self-medication (consumption of a food plant because it makes you feel better) or actual medical treatment (knowledge).[245] Almost all of the encountered plant species can be used in herbal medicine for various remedies. However, many of the plant taxa that were encountered as pollen in the coprolites have comparable medicinal purposes. Some species can be used in herbal treatments to aid the relief of cramps and promote food digestion (*Humulus lupulus* and Nymphaeaceae). Others are a laxative or cathartic (*Lonicera, Althaea officinalis,* and *Rhamnus cathartica*), or even a purgative (*Polypodium*). Some taxa are used in anthelminthic treatments (*Dryopteris*, *Osmunda regalis*, *Polypodium*, *Mentha*, *Filipendula vulgaris*, and *Artemisia maritima*). For example, a remedy derived from the roots of *Dryopteris dilatata* or *D. filix-mas* is one of the best-known herbal remedies for the treatment of tapeworms. The roots contain filicin, which paralyses tapeworms and other intestinal parasites. It is used as a worm expellant. The treatment is followed with a mild purgative to remove the worms from the body. Some taxa are used in herbal medicine to treat diarrhoea (*Filipendula ulmaria*: flowers; *Polygonum aviculare*: infusion of the plant; *Althaea officinalis*: flowers and root; *Calluna vulgaris*: flowers; *Plantago*: infusion of the plant; *Crataegus*: plant and fruits; *Hedera helix:* infusion of dried leaves; *Vaccinium:* leaves and fruits; *Rubus fruticosus:* flowers, leaves and fruits; *Ulmus:* bark infusion).[246] It is uncertain what medicinal knowledge the Swifterbant people had and what kind of remedies were used. In the intestinal parasites research at a Neolithic site in Switzerland near the Bodensee (Arbon Bleiche 3), many spores and sporangia of *Dryopteris* and *Polypodium* were observed. The researchers suggested that there may have been a medicinal purpose for their presence.[247] Animals or humans may have consumed these plants without knowing the medical properties but could have benefited from the results of the consumption of plants containing certain chemical compounds.[248] Also, The study of the mummy of the iceman Ötzi, found in the Alps, suggested that 5300 years ago this man was aware of the intestinal parasites in his body and that he treated himself with measured doses of a bracket fungus (*Piptoporus betulinus*). Analysis of the content of his rectum revealed *Trichuris trichiura* eggs. With the mummy of the iceman, two cork-like lumps were found which were pierced parts of the woody fruits of the fungus. It was suggested that he could fight the symptoms of his *Trichuris* infection by consuming the toxic resins of the fungus.[249]

With our current knowledge, it can be stated that various species which would have aided in the treatment of symptoms that are caused by helminthic infections, for example, diarrhoea, cramps and stomach ache, or function as a vermifuge (worm repellent) or a purgative (cleaning of the body), were growing in the surrounding vegetation or were possibly collected in vegetation further away.

243 Zeiler & Clason 1993.
244 Zeiler & Clason 1993.
245 Shurkin et al. 2014.
246 Van Os 1974; Starý & Jirasék 1990, Moerman 2009; Prendergast *et al.* 1998.
247 Le Bailly & Bouchet 2005.
248 Huffman & Vitazkova 2011; Shurkin 2014.
249 Capasso 1998.

11 Intestinal parasites

M. van der Linden

11.1 Introduction

In coprolites, in addition to the food remains of edible plants or bones from animals which may provide information about the diet and health of the organisms which excreted them, helminth eggs and remains of other intestinal parasites may also be well preserved. Helminths are parasitic worms, e.g. roundworms (nematodes), flukes (trematodes), and tapeworms (cestodes), which live in the intestines or other tissues of humans or animals. Some helminths can procreate in the human host, other helminths need other hosts in their life cycle. Humans can become infected with these worms by eating uncooked or undercooked meat of these host species (for example fish or pig).[250] Information about the diet of the infected person (or animal) can also be obtained in this way.

Helminthological research on desiccated faeces (coprolites) and mummies has been performed since 1944 but was redesigned in the 1980s.[251] Since then, methods have been improved and many new studies on coprolites and mummies have been done. However, most of the studied coprolite material originates from excavations in South America (Peru, Chile and Brazil), the southwestern United States, Egypt, Israel and South Korea, since these are the areas where coprolites are mostly found. Helminthological studies on intestinal material from mummies are mainly from China and South Korea, but some also come from Europe (Lithuania, Belgium, Germany, Poland and Denmark).[252] In Europe, helminthological research on latrines is more common.[253] In the Netherlands, not many helminthological studies, or palaeoecological studies, have been done on coprolites since human coprolites are rarely found in the Netherlands. The only known study is from 1979 when several coprolites from the Swifterbant excavations were studied for helminth eggs.[254] Twenty of the 44 samples contained recognisable worm eggs of nematodes (Trichuriidae) and trematodes (e.g. Fascioliidae and Opisthorchiidae). Coprolites from Hardinxveld-Giessendam De Bruin (Late Mesolithic - Early Neolithic) and Schipluiden-Harnaschpolder (Middle Neolithic) were studied palynologically, but no specific helminthological preparation or analysis was done.[255] A pollen slide prepared from a Bronze Age coprolite from Medemblik-Schepenwijk II did not contain helminth eggs - but it did contain many cereal pollen grains.[256]

For the current study, eight of the studied coprolites which were thought to be of human origin during the first assessment (see Chapter 4 for the selection procedure) and/or contained pollen of cereals, spores of dung fungi, or helminth eggs (found in the pollen analysis) were selected for helminthological research. The selected coprolites comprised one from Hardinxveld-Giessendam De Bruin (Early Swifterbant, Late Mesolithic - Early Neolithic, c. 5500-4300 cal BC) and seven from the Swifterbant excavation (Early Neolithic, 'classical' Swifterbant, c. 4300-4000 cal BC). Both sites were situated in a freshwater environment during the occupation or habitation phase. To the west of the sites, tidal plains and salt marsh environments were present (see Chapter 3 for more information about the sites). The coprolites studied in this research were collected from the cultural layer (dark humic clay) which had formed in the top of the levee.

11.2 Methods

11.2.1 Sample preparation

The coprolites selected for helminthological research were subsampled in the laboratory of BIAX *Consult* by selecting small pieces of gently crushed, dry, untreated coprolite material from the (unrinsed) samples which were first analysed for macro-remains (Table 11.1).[257] The volumes (ml) of all of the subsamples were determined. The subsamples were sent to the Sediment Laboratory of the Vrije Universiteit Amsterdam where the slides for compound light microscopy were prepared.

The samples were treated following the method for extracting intestinal parasite eggs from archaeological sediment samples adjusted for the rehydration time for coprolites.[258] Samples were rehydrated and disaggregated in a 0,5% trisodium phosphate aqueous solution (Na_3PO_4) for 96 hours. After 88 hours of rehydrating, the samples were gently stirred and

250 Garcia 2016.
251 Camacho *et al.* 2018; Reinhard, Hevley & Anderson 1987.
252 Camacho *et al.* 2018.
253 Mitchell 2017; Graff *et al.* 2020.
254 De Roever-Bonnet *et al.* 1979.
255 Bakels, Van Beurden & Vernimmen 2001; Bakels 2006. The pollen slides were all prepared with acetolysis.
256 Kooistra 2010. The pollen slides were all prepared with acetolysis.
257 Before the macrofossil analysis, the coprolites were cleaned on the outside with a scalpel to avoid contamination with recent material. Some of the coprolites were covered with ash.
258 Anastasiou & Mitchell 2013, with modifications described by Camacho *et al.* (2018); Lutz method for rehydration (adjusted for practical reasons in the laboratory) and Searcey method for helminth egg concentration (in this way the concentration can be compared to the pollen concentration).

Table 11.1 Data of the analysed helminth samples from the Swifterbant and Hardinxveld-Giessendam De Bruin coprolites.

Sample	Find	Material	Date (cal BC)	Volume (ml)	Labcode	Producer (GC-MS)
Hardinxveld	19952	coprolite	5500-4300	2	BXD9300	pig
S3-4	54655	coprolite	4300-3400	3	BXD9295	dog/human
S3-10	54845	coprolite	4300-3400	5	BXD9100	dog/human
S3-11	54827	coprolite	4300-3400	3	BXD9101	not faecal
S3-13	53814	coprolite	4300-3400	3	BXD9297	dog?
S3-28	54488	coprolite	4300-3400	5	BXD9298	human/ruminant
S4-1	1420	coprolite	4300-3400	3	BXD9299	n.d.
S4-4	629	coprolite	4300-3400	2	BXD9105	n.d.

legend: ncaf: no faecal matter detected, n.d.= no data.

Table 11.2 Helminth concentrations of Hardinxveld-Giessendam De Bruin and Swifterbant S3 and S4. n/ml = number of eggs per ml.

Samplenumber	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
Findnumber	**19952**	**54655**	**54845**	**54827**	**53847**	**54488**	**1420**	**629**
Labcode	**BXD9300**	**BXD9295**	**BXD9100**	**BXD9101**	**BXD9297**	**BXD9298**	**BXD9299**	**BXD9105**
Intestinal nematodes (roundworms)	(n/ml)	(n/ml)	(n/ml)	(n/ml)	(n/ml)	(n/ml)	(n/ml)	(n/ml)
Capillaria sp., egg	.	14	.	.	.	.	.	.
Dioctophyma sp., egg	.	.	.	.	.	.	9	6
Trichuris trichiura/suis (<59x28 µm)	.	.	141	121	27	3662	36	270
Intestinal cestodes (tapeworms)								
Diphyllobothrium sp., egg	.	.	103	138	.	.	.	.
Diphyllobothriidae(/ trematoda), (54-66 µm)	.	.	859	1120	.	99	.	.
Liver and lung trematodes (flukes)								
Opisthorchiidae, egg	.	.	.	17	.	119	9	6
Trematoda, indet., egg (> 86 µm)	97	.	.	.	.	.	.	.
Total concentration helminth eggs	97	14	1103	1396	27	3880	54	283

a few drops of 5% HCl were added to digest possible calcified remains (since bone fragments were present in the coprolites). After their rehydration, the samples were processed for thirty minutes in an ultrasonicator. To separate the parasite eggs from the other coprolite components, the samples were processed with a column of microsieves (150 µm and 20 µm). Following this, the material on the 20 µm sieve was placed in a 15 ml tube.[259] To calculate the helminth egg concentrations (the number of helminth eggs per ml), a known quantity of *Lycopodium clavatum* spores was added to each sample.[260] The residues were mounted in glycerol for microscopic analysis. For each sample, five microscopic slides were prepared. The remaining residues were stored for possible future analysis.

[259] Anastasiou & Mitchell 2013.
[260] Stockmarr 1971; Anastasiou & Mitchell 2013; Camacho *et al.* 2018. A tablet containing 18.407 *Lycopodium* spores was added to each sample.

11.2.2 Microscopic analysis of helminth eggs

The helminthological analysis was performed by using compound light microscopy (Olympus BX41) with a maximum magnification of 1000x. During the analysis the number of helminth eggs was quantified.[261] The length and width of the eggs were also measured. The percentage and concentration calculations were based on the total count of helminth eggs from five slides per sample (if present). In addition, pollen grains and spores of mosses, horsetails, and ferns and other microfossils (non-pollen palynomorphs such as fungal spores and algal remains) were identified and, if possible, quantified. If other microscopic remains such as tissue or phytoliths were found, their presence was noted. Identifications were made using standard literature and the reference collection of BIAX *Consult*.[262] The pollen concentration calculations were based on the total pollen count. The full counts are listed in Appendices VIII and IX. Since this preparation method is not ideal for pollen identification, these results are of indicative value. The additional pollen data are discussed in Chapter 10 together with the other pollen data and microfossils.

Figure 11.1 Large broken trematode egg (> 110 µm) found in the Hardinxveld-Giessendam De Bruin coprolite 19952 (scale bar: 10 stripes = 24.5 µm).

11.3 Results

The helminth composition in each sample is described below following the interpretations of Garcia, Thienpont *et al.* and Mehlhorn.[263] The helminth concentrations are presented in Table 11.2. The average sizes of *Trichuris* eggs are listed in Appendix XI and the original helminth counts are presented in Appendix XII. The oldest sample from the Late Mesolithic Hardinxveld-Giessendam De Bruin site is discussed first, followed by the samples from the Early Neolithic Swifterbant sites S3 en S4.

11.3.1 Hardinxveld-Giessendam De Bruin 19952

Very few helminth eggs are present in the coprolite from Hardinxveld-Giessendam De Bruin 19952 (97 eggs/ml). The concentration is based on the finds of two broken remains of rather large helminth eggs which appear to be of trematode origin. The fragments of one egg had a minimum length of 86 µm. The other one was at least 110 µm long, meaning that the entire egg would have been larger (Fig. 11.1). At one pole, a knob (a kind of thickening) was visible. These eggs are possible of the trematode family Fascioliidae (including *Fasciola hepatica*). *Fasciola hepatica* is the most common and important liver fluke and has a global distribution in cooler climates. The infective form of these flukes is released by snails on herbage. The infection of hosts, mainly sheep and cattle but also humans, is usually caused by the ingestion of infected marsh plants (such as watercress).[264]

11.3.2 Swifterbant S3-4

The parasite sample from the Swifterbant S3-4 coprolite has a very low concentration of helminth eggs (14 eggs/ml). This is based on the find of one egg of hairworm (*Capillaria* sp). (Fig. 11.2). Hairworm species have various hosts ranging from fish, gamebirds to chickens and ducks, to ruminants, carnivores, rodents and humans. The life cycles of *Capillaria* species are

[261] Thienpont, Rochette & Van Parijs 1986; Garcia 2016; Mehlhorn 2016.
[262] Thienpont, Rochette & Van Parijs 1986; Garcia 2016; Mehlhorn 2016; Ash & Orihel 1997; Polderman 2005; Beug 2004; Moore, Webb & Collinson 1991; Punt *et al.* 1976-2009, Weeda *et al.* 1985-1994; Van Geel 1978; Henry 2020.
[263] Garcia 2016; Thienpont, Rochette & Van Parijs 1986; Mehlhorn 2016.
[264] Garcia 2016.

Figure 11.2 *Capillaria* sp. egg in S3-4 parasite slide (scale bar: 10 stripes = 24.5 µm).

complex, so not many conclusions can be drawn about the host.[265] The eggs of *Capillaria hepatica*, for example, are nested in the liver tissue of animals and are not excreted. They are transferred via the consumption of meat of animals.[266] When these eggs are consumed along with meat, the eggs are passed with the faeces and thus can be found in the soil. The eggs of other species are excreted and can also be found in the soil or drinking water. Eggs of *Capillaria* species are hard to distinguish from one another, but different morphotypes may be recognised. The egg found at Swifterbant had a punctuated shell. Eggs with this morphotype are associated with species that parasitise ichthyofauna.[267] *Capillaria brevispicula*, for example, is found in the intestine of cyprinids and some other freshwater fish such as eel (*Anguilla anguilla*).[268]

11.3.3 Swifterbant S3-10

Three types of helminth eggs could be distinguished in S3-10: whipworm *Trichuris trichiura* (or *T. suis*) (141 eggs/ml), fish tapeworm *Diphyllobothrium latum* (103 eggs/ml), and Diphyllobothriidae (859 eggs/ml). The total helminth egg concentration (1103 eggs/ml) is relatively high in comparison with the other coprolites.

The nematode *Trichuris trichiura* has humans as the final host, while nematodes of *T. suis* are found in the intestines of pigs (and sometimes humans). The size of the eggs of species *T. trichiura* (50-58 µm x 21-27 µm) overlaps with that of *Trichuris suis* (50-68 µm x 21-31 µm), although eggs of *T. suis* can be much bigger.[269] The mean size of the eleven *Trichuris* eggs is 49.8 x 26.1 µm, which points to *T. trichiura* (with humans as the final hosts), but *T. suis* (pig) cannot be excluded. The eggs of the *Trichuris* species occur in soils with faecal matter.[270] Infection of the host occurs by the ingestion of the eggs due to poor hygienic conditions, e.g. via unwashed food or infected drinking water or via direct contact with the contaminated soil.

Some eggs (eight) could be identified as *Diphyllobothrium* (fish tapeworm); these eggs all have a specific knob at one pole (Fig. 11.3).

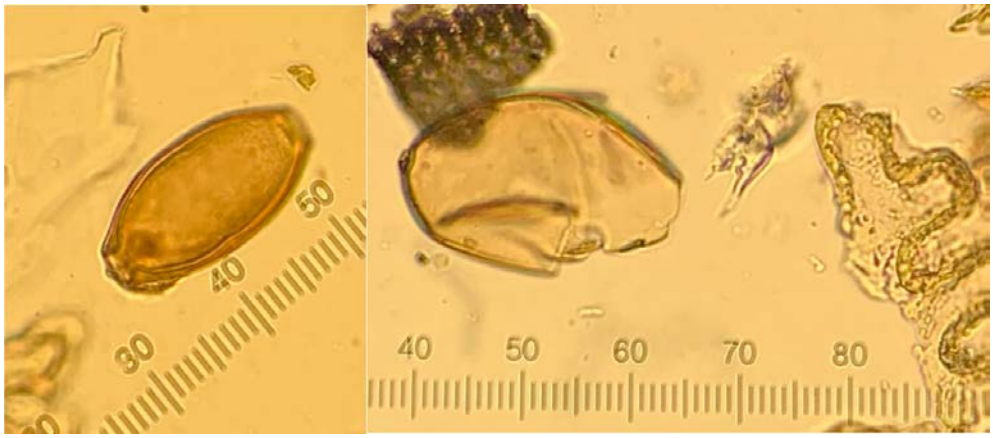


Figure 11.3 Left: *Trichuris trichiura/suis* egg, right: *Diphyllobothrium* sp. egg with knob on the left pole in S3-10 parasite slide. Fragments of *Nymphaea* seed testa are also visible (scale bar: 10 stripes = 24.5 µm).

265 Le Bailly & Bouchet 2005.
266 Mehlhorn 2016, 381-382.
267 Thienpont, Rochette & Van Parijs 1986; Polderman 2005, Moravec 1980, Le Bailly & Bouchet 2005.
268 Moravec 1980.
269 Thienpont, Rochette & Van Parijs 1986; Mehlhorn gives a slightly different range of *T. trichiura* (50-55 µm x 21-25 um) and *Trichuris suis* (45-75 µm x 27-35 um).
270 Garcia 2016; Le Bailly & Bouchet 2005.

The size of the eggs points to *Diphyllobothrium latum* or *D. dendriticum*.[271] The other 67 operculated eggs most probably also belong to Diphyllobothriidae. Possibly, some of these operculated eggs, of which the specific knob could not be seen, are of the trematode family. The final hosts of Diphyllobothriidae tapeworms are humans, cats, and dogs. The intermediate hosts are crustaceans, fishes, raptor fishes, piscivorous (fish-eating) birds, and piscivorous mammals. The infection of humans occurs via ingestion of raw or poorly cooked, smoked, or pickled freshwater fish (such as pike or perch) or marine fish that spawn in fresh water (such as salmon).[272]

11.3.4 Swifterbant S3-11

The helminth taxa present in S3-11 resemble those of S3-10: *Trichuris trichiura /suis* (121 eggs/ml), *Diphyllobothrium* sp. (138 eggs/ml) and Diphyllobothriidae (1120 eggs/ml). In addition, eggs of Opisthorchiidae (17 eggs/ml) are found. The helminth egg concentration is slightly higher than that of coprolite S3-10 (1396 eggs/ml).

The mean size of the eight whipworm *Trichuris* eggs is 51.4x25.8 µm, which points to *T. trichiura*. Eight eggs can be identified as *Diphyllobothrium latum* (fish tapeworm); these eggs all have a specific knob at one pole (Fig. 11.4). The other 65 eggs most probably are also of Diphyllobothriidae (although some may be small trematode eggs).

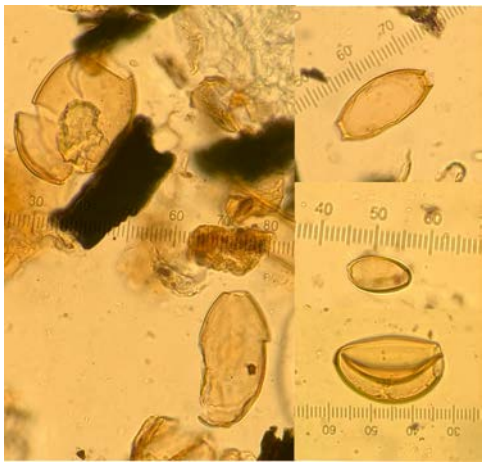


Figure 11.4 Left: Diphyllobothriidae eggs, top right: *Trichuris trichiura/suis* egg, right middle: Opisthorchiidae egg; bottom right: *Diphyllobothrium* egg in S3-11 parasite slides (scale bar: 10 stripes = 24.5 µm).

The Opisthorchiidae family (liver flukes) is represented by one egg in sample S3-11 (Fig. 11.4). The final hosts of these trematodes are humans and mammals which eat raw fish (such as cats, dogs, marters, badgers, mink, weasels and rats). Infections take place through ingestion of the metacercariaea (intermediate stage) of Opisthorchiidae in infected raw or undercooked freshwater fish.[273]

11.3.5 Swifterbant S3-13

The parasite sample from coprolite S3-13 has a low helminth egg concentration (27 eggs/ml). Only *Trichuris trichiura* (or T. *suis*) eggs are present (Fig. 11.5). The mean size of the two *Trichuris* eggs is 56.5 x 24.5 µm, which points to *T. trichiura* (with humans as final hosts), but *T. suis* (pig) cannot be excluded.

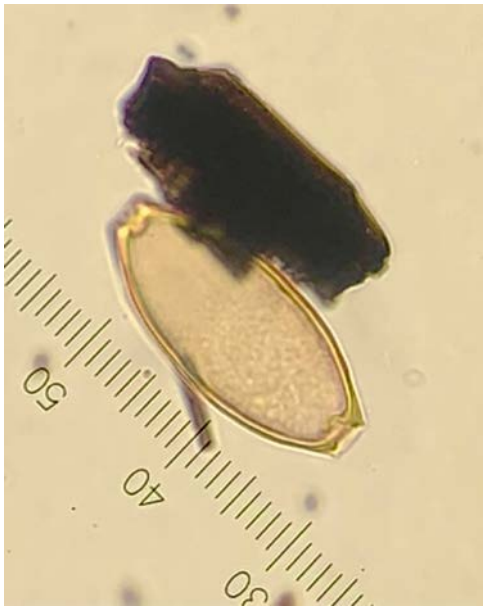


Figure 11.5 *Trichuris* egg and charred remains in S3-13 parasite slides (scale bar: 10 stripes = 24.5 µm).

11.3.6 Swifterbant S3-28

The parasite sample from the S3-28 coprolite contains the highest concentration of helminth eggs of all of the studied coprolites (3880 eggs/ml). The helminth eggs are of at least three taxa (Fig. 11.6): *Trichuris trichiura/suis* (3662 eggs/ml),

[271] Lestinova *et al.* 2016. Or *D. nihonkaiense*, but this tapeworm is endemic to Japan.
[272] Garcia 2016.
[273] Garcia 2016.

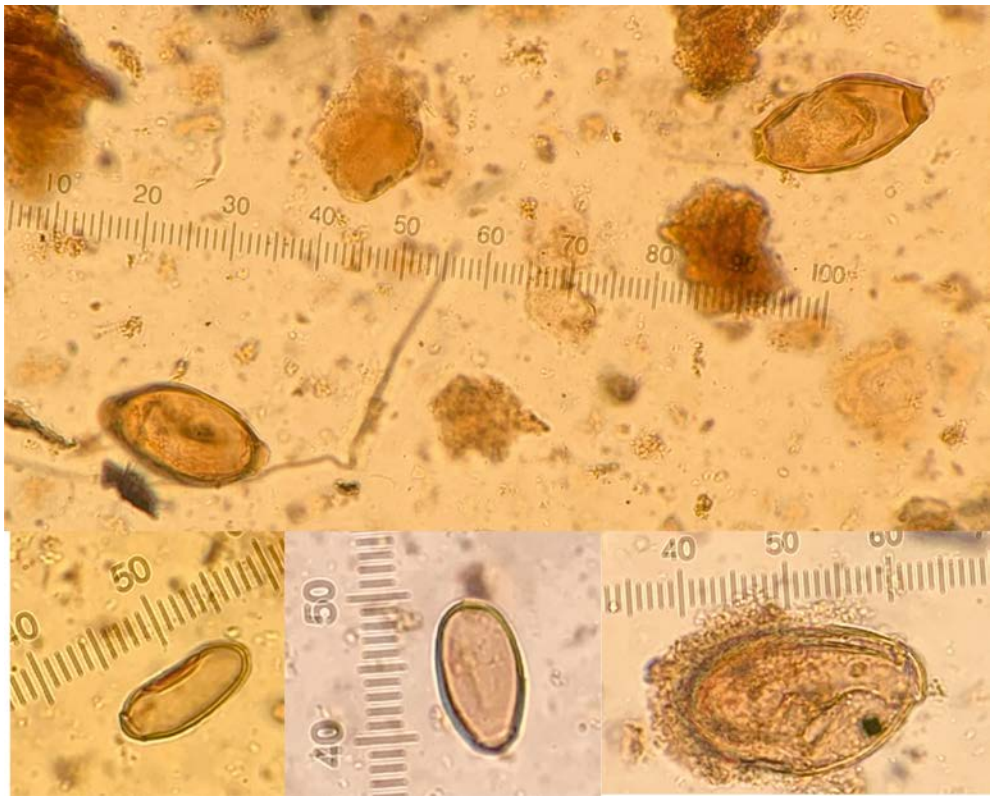


Figure 11.6 Top: *Trichuris* eggs, bottom left and middle: Opisthorchiidae egg, bottom right: cf. Diphyllobothriidae egg (operculum on the right) from S3-28 parasite slides (scale bar: 10 stripes = 24.5 µm).

Diphyllobothriidae (99 eggs/ml) and Opisthorchiidae (119 eggs/ml).

All 184 *Trichuris* eggs, except one, were smaller than 58 µm in length. One measured 58.9 x 28.2 µm. The mean size of the *Trichuris* eggs in this coprolite is 52.1 x 26.1 µm, which points to *T. trichiura* (with humans as the final hosts).

Several eggs of Opisthorchiidae trematodes (six) were found in sample S3-28. The larger operculated helminth eggs (five eggs) can probably be attributed to Diphyllobothriidae (or possibly be small trematode eggs). The size of the operculated eggs points to *D. denditricum*.[274] The final hosts of both Diphyllobothriidae and Opisthorchiidae are humans, cats, and dogs (infection by ingestion of contaminated fish).

11.3.7 Swifterbant S4-1

The helminth concentration in the parasite sample from the S4-1 coprolite is relatively low (54 eggs/ml) in comparison with those from coprolites S3-10, S3-11 and S3-28. In the S4-1 coprolite, at least four helminth types were distinguished: *Dioctophyma* sp. (9 eggs/ml), *Trichuris trichiura/suis* (36 eggs/ml), Opisthorchiidae (9 eggs/ml), and free-living nematode (63 eggs/ml).

The average size of the *Trichuris* eggs in the parasite sample from coprolite S4-1 is 48.1 x 27.4 µm, which points to *T. trichiura* (with humans as the final hosts). One egg of Opisthorchiidae trematode is present.

In the Swifterbant-S4 coprolites, two other nematode taxa are present of which no eggs were found in the S3 coprolites. One egg of *Dioctophyma* sp. (kidney worm) is present (Fig. 11.7). Kidney worms live in the kidneys of dogs, cats, foxes, mustelids and wolves. They are less common in humans and swine (nowadays). The eggs are excreted in urine. Outside the body, in fresh water or humid soil, the larva hatches inside the egg. The second stage larva only hatches when the eggs have been ingested by intermediate hosts (oligochaetes, earthworms, annelids or crustaceans). Fish or frogs can also be transporters of the larva. When ingested by

[274] Lestinova *et al.* 2016.

dogs or humans, the larva enters the abdominal cavity and penetrates into the kidneys.[275]

In the parasite sample from S4-1 coprolite, eggs and a worm of a free-living nematode are present. These small worms, which live in soil, feed on bacteria, algae, fungi, dead organisms, and living tissues. The most logical explanation for the presence of free-living nematodes is the immediate contamination of the faeces when it was dropped on the ground. The free-living nematodes in the soil can easily penetrate the faeces and thus become part of the coprolite during early mineralisation. It is less likely that these eggs were consumed, although it cannot be excluded since many nematodes infect plant tissue and contact with the soil obviously happened. It seems unlikely that the penetration of free-living nematodes (including eggs with larva) happened after mineralisation took place.

11.3.8 Swifterbant 4-4

The parasite sample from the S4-4 coprolite has a moderate helminth concentration (282 eggs/ml). Eggs of three helminth taxa are present: *Dioctophyma* sp. (6 eggs/ml), *Trichuris trichiura/suis* (270 eggs/ml) and Opisthorchiidae (6 eggs/ml) (Fig. 11.8).

11.4 Discussion

11.4.1 Which intestinal parasites are present?

Hardinxveld-Giessendam De Bruin
In the Hardinxveld-Giessendam De Bruin coprolite 19952, large helminth eggs are present which probably are of trematode origin, possibly of *Fasciola hepatica*. These trematodes need intermediate hosts in their life cycle. Infection of the final hosts follows the consumption of infected herbage.

Swifterbant
In the Swifterbant-S3 parasite assemblage, five helminth taxa are present which all differ from those found at Hardinxveld-Giessendam De Bruin. The eggs of the cestode family Diphyllobothriidae, including *Diphyllobothrium* sp. and the trematode family Opisthorchiidae, were encountered. Both the tapeworms and flukes need intermediate hosts in their life cycle (freshwater fish). Eggs of the intestinal nematodes *Trichuris trichiura/suis* and *Capillaria* are also present. Single host infections by *Trichuris* occur via contact with the eggs in contaminated soil, drinking water or dirty food plants. *Capillaria* infections depend on the species, but may occur via contaminated soil or food.

Figure 11.7 Top left: *Dioctophyma* sp., bottom left: larva or worm of free-living nematode, right: worm of free-living nematode from S4-1 parasite slides (scale bar: 10 stripes = 24.5 µm).

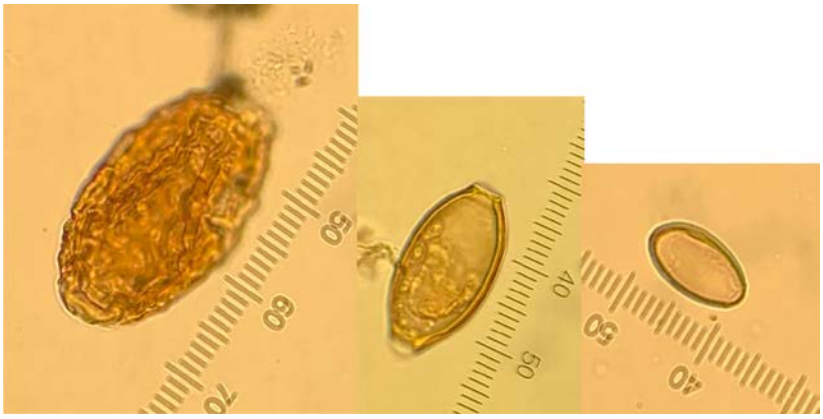


Figure 11.8 Helminth eggs of *Dioctophyma sp.* (left), *Trichuris* (middle), and Opisthorchiidae (right) from S4-4 parasite slides (scale bar: 10 stripes = 24.5 µm).

[275] Mehlhorn 2016, 451-452.

In the Swifterbant-S4 parasite assemblage, eggs of the tapeworms, flukes and intestinal nematodes found at the S3 site are also present. In addition, eggs of the intestinal nematode *Dioctophyma* sp. were found in both S4 coprolites. Infections of *Dioctophyma* sp. occur when infected fish or frogs have been eaten by dogs or humans.

11.4.2 What is the origin of the helminth eggs in the coprolites?

Most helminths have rather complicated life cycles in which one or several intermediate hosts are involved and intermediate life stages occur before they develop into the adult stage. The adult worm grows in the final host. The eggs of helminths are formed in the adult worm and are passed in the faeces of the final host.[276] Therefore, the presence of helminth eggs in coprolites generally indicates that the faeces were produced by the final host. Using the current knowledge about the final hosts of the helminth species, the eggs encountered in the Hardinxveld-Giessendam and Swifterbant coprolites can help deduce whether the coprolites are of human or animal origin.[277]

In some cases, however, eggs may be passed in the faeces of animals that are not the host of the helminths involved; this is called spurious passage. This may happen when a carnivore has eaten meat from contaminated organs and, perhaps, after drinking contaminated water. Also, dogs are coprophagous, which means that dogs may eat faeces. When dogs eat contaminated faeces, the spurious passage of eggs of another host in the dogs' faeces can also occur.

In Table 11.3, all the possible final hosts of the helminth species present in the studied coprolites are shown. It is remarkable that for all of the helminth taxa encountered, humans can be the final host. Based on the composition of helminth eggs, the Hardinxveld-Giessendam De Bruin coprolite was probably produced by a herbivore (most likely sheep or goat, but other herbivorous or omnivorous mammals are also possible). This is in concordance with the lipid analysis (which points to pig as producer), because pigs eat a mixed diet including herbage.

In the Swifterbant parasite sample from coprolite S3-4, one *Capillaria* egg is present. Since the species could not be identified, it is not certain which host was the producer. Based on the morphotype, it could possibly be a fish-eating mammal.

[276] The eggs of some species such as *Dioctophyma renale* are excreted in urine. *Capillaria hepatica* eggs are not passed by their hosts, but remain in liver tissue.

[277] Carvalho Gonçalves, Araújo & Ferreira 2003.

Table 11.3 Helminth infections of Hardinxveld-Giessendam De Bruin and Swifterbant-S3 and -S4. Overview of possible hosts (pisc.= piscivorous = fish eating; herb.= herbivorous = plant eating; m = mammals) based on the presence of various helminth infections.

Samplenumber	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
Findnumber	**19952**	**54655**	**54845**	**54827**	**53814**	**54488**	**1420**	**629**
Labcode	**BXD9300**	**BXD9295**	**BXD9100**	**BXD9101**	**BXD9297**	**BXD9298**	**BXD9299**	**BXD9105**
Capillaria sp.	.	various	.	.	.	.	.	.
Dioctophyma sp.	.	.	.	.	.	.	dog (human)	dog (human)
Trichuris trichiura(/ suis) (<59x28 µm)	.	.	human (pig)	human (pig)	human (pig)	human (pig)	human (pig)	human (pig)
Diphyllobothriidae	.	.	human, cat, dog	human, cat, dog	.	human, cat, dog	.	.
Opisthorchiidae	.	.	.	human, cat, dog, pisc. mammal	.	human, cat, dog, pisc. mammal	human, cat, dog, pisc. mammal	human, cat, dog, pisc. mammal
Trematode, Possibly Fasciola hepatica	human, most common in sheep, also goat and other herbivorous mammals	.	.	.	.	.	.	.
Most probable origin helminth eggs	herbivore?	?	human (pig), dog	human (pig), dog	human (pig)	human (pig), dog	human (pig), dog	human (pig), dog

In coprolite S3-13, only eggs of *Trichuris trichiura/suis* are present. These eggs are probably from a human host. However, if a dog ate human faeces, it could have produced this coprolite as well. Therefore, coprolite S3-13 is probably of human origin (or pig) - or possibly of dog.

In the other Swifterbant coprolites, S3-10, S3-11 and S3-28, in addition to *Trichuris*, Diphyllobothriidae (*Diphyllobothrium* sp.) and Opisthorchiidae eggs are also encountered. The final hosts of these species are infected by the consumption of contaminated freshwater fish. The most common final hosts are humans, dogs, and cats. Other than these, swine, mustelids and other piscivorous mammals can serve as hosts.[278] Since *Trichuris trichiura/suis* eggs are also present - and do not have dogs and cats as hosts - a human (or pig) seems to be the most logical final host. However, if dogs had been eating faeces, dogs, too, could have produced the stools.

In the Swifterbant S4-1 and S4-4 coprolites, eggs of *Dioctophyma* sp. are present in addition to the species already mentioned. Dogs (and humans) are the most common final hosts. The coprolites from the S4 site can therefore also have been produced by either a dog, a human, or, possibly, a pig.

11.4.3 Health

Hardinxveld-Giessendam De Bruin

At Hardinxveld-Giessendam, two large trematode eggs (possibly Fascioliidae) were found. Fascioliidae species can occur in pigs as well as in humans as the final hosts. Hosts become infected by the ingestion of raw or undercooked food. The presence of *Fasciola hepatica* (liver fluke) indicates the consumption of raw or undercooked metacercariae-contaminated aquatic vegetation, e.g. watercress. After ingestion, the intermediate stage fluke migrates to the host liver where it matures into an adult fluke and produces eggs. Detection of *Fasciola* eggs in the faeces of carnivores can also represent spurious passage following consumption of contaminated liver. During the infection of *Fasciola*, symptoms of Fascioliasis may or may not occur. In the first stage of larval migration, symptoms associated with inflammation, tissue destruction, and toxic or allergic reactions can occur. Abdominal pain, nausea, vomiting, hepatomegaly, malaise, fever, and cough may develop. During chronic infection (after months or years), inflammation or blockage of bile ducts, the gallbladder or pancreas may occur.[279]

Swifterbant-S3

In the coprolites from Swifterbant-S3, five helminth taxa are present. In almost all of the coprolites from S3, eggs of *Trichuris trichiura/suis* are present. *Trichuris* (whipworm) has no intermediate host in its life cycle. The hosts are contaminated with eggs via the soil due to poor hygienic conditions or via contaminated food or drinking water. The symptoms of Trichuriasis are mild (chronic diarrhoea, irritated intestines, and hypochromic anemia).[280] Females of *Trichuris* produce many eggs, up to 15,000 per day.[281] The egg in S3-4 resembles *Capillaria* (hairworm). Some *Capillaria* species have a direct life cycle and need no intermediate host. Humans are usually infected after ingesting embryonated eggs in faecally contaminated water or soil or via consumption of infected meat. Rodents (and carnivores) can become intermediate hosts by eating infected meat and spreading eggs with their faeces. *Capillaria* infections are rare nowadays but may be fatal due to liver infection.[282]

The infection with *Diphyllobothrium latum* (fish tapeworm) and Opisthorchiidae (liver fluke) also occurs through the ingestion of raw, smoked, or undercooked freshwater fish. Diphyllobothriasis can be a long-lasting infection (up to 25 years). Most infections are asymptomatic but gastrointestinal symptoms may occur. Massive infections may cause intestinal obstruction, although this is rare.[283] The symptoms of Opisthorchiasis, for example following infection with *Opisthorchis filineus* (cat liver fluke), are related to the worm burden. In mild cases, mild abdominal symptoms occur. Patients with a high worm burden have abdominal pain and various somatic symptoms (headache and dizziness). With a longer duration, symptoms can become severe: hepatomegaly (enlargement of the liver), malnutrition, pancreatitis, and liver abscesses may develop.[284]

The producers of the Swifterbant-S3 coprolites S3-10 and S3-11, may have suffered from the worst *Diphyllobothrium* infection,

278 Garcia 2016.
279 Garcia 2016.
280 Garcia 2016, 311-314.
281 Mehlhorn 2016, 378.
282 Garcia 2016, 315-316.
283 Garcia 2016, 422-424.
284 Garcia 2016, 487-499. This also involves symptoms of clonorchiasis.

whereas the producer of the S3-28 coprolite, probably suffered from the highest worm burden of *Trichuris* and Opisthorchiidae. Which of these, possibly severe, symptoms were present depends on whether or not the infection was chronic or untreated.

In the Swifterbant-S3 coprolites S3-10 and S3-11, more than 1103 and 1396 eggs, respectively, were recovered per ml. The S3-28 coprolite has the highest concentration of eggs: 3880 eggs per ml. In comparison to the helminth egg concentration in medieval cesspits, however, this may not be high. In some cesspits, between 75 to 39,640 *Trichuris* eggs per gram were found.[285] However, cesspit fillings are a concentrate of many faecal events. When comparing the helminth egg concentration in the S3-28 coprolite to the pinworm concentration in coprolites from La Cueva de los Muertos Chiquitos, it is high since most coprolites contained 0-100 eggs per gram while very few coprolites contained higher concentrations (ranging to up to 1000-2000 eggs per g).[286] In the coprolite study of the Neolithic site Arbon-Bleiche 3, no helminth concentrations are mentioned.[287] Though the concentration of helminth eggs may not be extremely high, it does show that producers may have suffered multiple worm infections. In some studies on American sites, an increased worm egg concentration in the soil of the settlements, reflected in the coprolites, is mentioned as a reason to abandon the sites.[288]

Swifterbant-S4

In the two studied coprolites from the Swifterbant-S4, in addition to the helminths found at the Swifterbant-S3 (*Trichuris trichiura/suis*, Diphyllobothriidae/*Diphyllobothrium* sp. and Opisthorchiidae) one other helminth species is present. In both coprolites from the S4 site, eggs of *Dioctophyma* sp. were found. These worms grow in the kidneys and in the pleural cavity of the hosts.[289] Infections with kidney worms are severe since the kidneys are gradually destroyed, which may lead to the death of the host.[290]

Without treatment, these parasitic worm infections probably led to serious health issues. In the coprolites, pollen and spores of several plants which can be used as an herbal medicine with anthelminthic properties (for example *Dryopteris* and/or *Polypodium* root infusion) or against diarrhoea (*Althaea officinalis*) were found (see Chapter 10). It is unknown whether the Swifterbant people were aware of these remedies. Perhaps (unaware) self-medication was practiced (consumption of plants not for food but to feel better)? This is further discussed in Chapter 10 and the Synthesis.

The species composition of helminths at Swifterbant-S4 differs slightly from the Swifterbant-S3 sites, but in general comprises of the same species. The concentration of helminth eggs is lower in the S4 coprolites than in some of the S3 coprolites, though. The presence of *Trichuris* eggs, which spread through contaminated soil (geohelminths) at Swifterbant indicates that faecal matter was present in the soil.[291] This may point to long-term or permanent use of the site and a high population density.[292] In this way, infection occurred via contact with contaminated soil (poor hygiene), food plants, or drinking water. In addition, the consumption of raw or undercooked fish caused tapeworm or fluke infections. Overall, the hygienic conditions were poor at the Swifterbant site.

11.4.4 Community diet

In almost all of the coprolites, helminth eggs are present which are probably from a human host (*Trichuris trichiura*). The stools, however, may have been from dogs (or pigs). Since pigs and dogs often eat the same food (and/or food waste) as humans, the composition of the coprolites can be used to establish the community diet.[293]

Hardinxveld-Giessendam De Bruin

Because the trematode present in Hardinxveld-Giessendam 19952 has intermediate hosts in its life cycle, the findings of these eggs also provide information about the diet. It shows that raw and/or undercooked aquatic vegetation was consumed. It may possibly imply the consumption of raw and/or undercooked infected meat.

The absence of nematode eggs, which are spread by contact with contaminated soil (geohelminths), in the coprolite of Hardinxveld-Giessendam De Bruin is curious. Since the supposed producer is a pig, one might expect eggs of *Trichuris suis*. These were not present, but cf. Fascioliidae eggs were. In the earlier intestinal

[285] Graff *et al.* 2020.
[286] Camacho *et al.* 2018.
[287] Le Bailly & Bouchet 2005.
[288] Reinhard, Hevley & Anderson 1987. No specific concentration is mentioned.
[289] Mehlhorn 2016, 452.
[290] Jacomet, Leuzinger & Schibler 2005, 409.
[291] Le Bailly & Bouchet 2005.
[292] Reinhard *et al.* 2013.
[293] Witt *et al.* 2021.

parasites study of Swifterbant, Fascioliidae eggs were present in four coprolites, one of which also contained eggs of Trichuriidae.[294] Although only one coprolite was studied, and the variance may be explained by different hosts, the absence of geohelminths is noted.

Swifterbant-S3 and -S4

The infections with Diphyllobothriidae (*Diphyllobothrium latum*) and Opisthorchiidae imply that the people at the S3 site ate freshwater fish such as pike and perch or marine fish that spawn in fresh water such as salmon. The infections of *Dioctophyma* can also happen via the consumption of frogs. Fish would have been eaten raw or cooked (but sometimes undercooked). These results comply with the finds of fish bones (see Chapter 7). The micro-CT scans showed that entire fish was cooked (see Chapter 6). Food preparation with entire fish may have increased infections with Diphyllobothriidae.[295]

The presence of nematode eggs of *Trichuris trichiura* implies that the soil and drinking water was contaminated with the eggs. This indicates the presence of faecal matter in the soil.[296] The presence of faecal matter in the cultural layer is also shown by the high concentration of dung fungi at the S4 site.[297] This also implies that people (and animals) were living at the same site for a longer time. Furthermore, the frequent presence of *Trichuris* is promoted by a lifestyle based on the consumption of cultivated plants and the domestication of animals.[298] The consumption of cultivated plants is strengthened by the finds of cereal pollen (S3-4) and cereal bran (S3-10), which proves the consumption of grains.[299]

The most ancient finds of geohelminth eggs date back to hunter-gatherer communities. Geohelminth *Trichuris trichiura* is a heirloom parasite which was dispersed from Africa following human migrations to Asia and Europe.[300] It was present in the New World in prehistoric times before European colonists arrived.[301] It was hypothesised that the first settlers used a sea-route along the southern coast of the Bering land bridge. The settlers had vessels and were able to navigate near-shore waters.[302] Whether by a transoceanic route or coastal navigation, prehistoric settlers brought such soil-transmitted helminths to the New World in a journey no longer than the life-span of these helminths.[303] In the rectum of the mummy of the 5300 years old mummy of the Ice man found in the Alps, *Trichuris trichiura* eggs were present.[304] The earliest finds of *Trichuris* eggs in the Netherlands were reported in Swifterbant-S3 coprolites (4300-4000 cal BC) by De Roever-Bonnet.[305] Other coprolites from this site were further examined in that study. In other archaeological sites in southern Europe, soil-transmitted helminths (the faecal-borne parasite *Trichuris,* for example) and intermediate host-transmitted helminths (zoonotic parasites such as *Taenia* and *Diphyllobothrium*) were found in older Neolithic sites in Cyprus (Shillourokambos: 8300-7000 BC, Khirokitia: 7000-6000 cal BC), Spain (La Draga: 5320-4980 cal BC), and Arbon-Bleiche 3 (3385-3370 cal BC).[306] The helminth species composition found in Arbon-Bleiche 3 is almost the same as at Swifterbant-S3 and -S4. In a palaeoparasitological study of coprolites and soil samples of a Neolithic site (7100–6150 cal BC) of the early village of Catalhöyük in Turkey, *Trichuris trichiura* eggs were also reported.[307] The frequent presence of *Trichuris* eggs is a good indication of the Neolithic way of life at the Swifterbant settlement. It is possible that the hunter-gatherers from the Swifterbant area were already infected with *Trichuris* and that infections raised when they settled at Swifterbant. The presence of *Trichuris* eggs at the site may also imply that the Swifterbant people were in contact with other people with a Neolithic lifestyle (and a faecal-contaminated settlement), or that a contaminated site was visited, or that infected humans migrated to the site. Geohelminth *Trichuris* does not spread by itself but travels with its hosts (humans, in the case of *Trichuris trichiura*).[308] Contact with contaminated sites (and people) may occur during trading activities or migration of people, for example by canoe or boat. This will be further discussed in the synthesis (Chapter 12).

The presence of both soil-spread intestinal nematodes and intestinal parasites that depend on intermediates hosts (freshwater fish) shows that the Swifterbant lifestyle and diet were coupled with the hunting of wild animals and the gathering of wild produce. The diet of the people from the S4 site did not differ much from that of the people from the S3 site.

294 De Roever-Bonnet *et al.* 1979.
295 Mitchell 2017. A link was made with the preparation of the uncooked Roman fish sauce *garum*.
296 Le Bailly & Bouchet 2005.
297 Van der Veen 2008.
298 Ledger *et al.* 2019.
299 See also other finds of cereal remains in the SEM (Chapter 8), phytoliths (Chapter 9), and pollen (Chapter 10).
300 Hawash *et al.* 2016, Mitchell 2013, Carvalho Gonçalves, Araújo & Ferreira 2003.
301 Carvalho Gonçalves, Araújo & Ferreira 2003.
302 Dixon 2001; Steverding 2020.
303 Carvalho Gonçalves, Araújo & Ferreira 2003.
304 Capasso 1998.
305 De Roever-Bonnet *et al.* 1979.
306 Harter-Lailheugue *et al.* 2005; Maicher *et al.* 2017, Le Bailly & Bouchet 2005; Le Bailly, Schlichtherle & Leuzinger 2005.
307 Ledger *et al.* 2019.
308 Mitchell 2013; Hawash 2016; Steverding 2020.

11.5 Conclusions

The helminth composition of eight coprolites from Hardinxveld-Giessendam and Swifterbant was analysed. In total, the eggs of at least six different helminth taxa were identified. In the Hardinxveld-Giessendam De Bruin coprolites a different helminth composition was present than in the examined Swifterbant coprolites. In Hardinxveld-Giessendam, only helminths (likely Fascioliidae) that spread via consumption of contaminated aquatic vegetation (or possibly via the consumption of contaminated flesh) are present. However, since only one coprolite from Hardinxveld-Giessendam was analysed no convincing conclusions can be drawn.

In both Swifterbant sites S3 and S4, helminths of Diphyllobothriidae (including *Diphyllobothrium*) and Opisthorchiidae are present. These infect (human) hosts through the consumption of contaminated freshwater fish such as pike, perch and salmon. Possibly, frogs were also eaten. The presence of *Dioctophyma* may be an indicator that dogs were kept at the site. Helminths that infect (human) hosts via eggs in contaminated soil were also present at Swifterbant. The frequent presence of *Trichuris trichiura/suis* indicates the fouling of the soil with faeces, which implies the long-term presence of humans (and animals) at the site.

At the S4 site, a slightly other variety of intestinal parasites is present (but lower egg concentrations per ml of coprolite material). The assemblages from both the S3 and S4 sites resemble each other, but, based on the helminthological composition, are not exactly the same. The difference may be explained by different hosts - or perhaps in chronology. Although the helminth assemblages are not exactly the same, it is very well possible that the S3 and S4 sites belonged to the same settlement, as proposed by Raemaekers & De Roever.[309]

This study of the Swifterbant coprolites brought additional information (the taxa *Diphyllobothrium*, *Capillaria,* and *Dioctophyma*) on the helminthological composition of the coprolites to the study that was done in 1979.

[309] Raemaekers & De Roever 2020.

12 Starch granule analysis

K. Hardy

12.1 Introduction

Thirteen coprolites were subsampled to investigate the presence of starch granules (Table 12.1). Starch occurs as granules of variable size and shape, made up of two types of polymers of D-glucose: amylose and amylopectin. The recovery and identification of starch granules from archaeological contexts is now widely used to identify the presence of plants. However, starch granules vary considerably in size and shape (both between and within species) while the expression of multiple genes during plant growth are affected by local conditions, therefore using their morphology to identify probable plant source has limitations.[310] There have been a small number of studies of starch granules recovered from coprolites; most of these are summarised in Shillito *et al*.[311] They include identification of starch granules in human and/or dog from Polynesia and various sites in North and South America.[312]

12.2 Method

Approximately 0.05 g of sample were placed in Eppendorf tubes and 1 ml 5% Calgon was added to deflocculate overnight. Samples were vortexed then centrifuged and the supernatant removed. Samples were left overnight to dry. Afterward, 1 ml of heavy density polytungstate at 1.75 density was added and samples were left for 2 hours. Samples were vortexed, then centrifuged at 10,000 for 3 minutes. The surface layer was extracted and placed in 1 ml water to wash. The samples were centrifuged and the supernatant was extracted. The residue was placed on microscope slides and mounted in 50% glycerol. Two 22 x 22 mm slides were examined for each sample. A second run of samples using the same protocol was also conducted, and the results are a combination of both analyses. Additionally, samples of residue and supernatant were also tested but here, no additional starch granules were detected.

Table 12.1 Material recovered from samples.

Coprolite code	Sample number	Material	Producer (GC-MS)	Results
Hardinxveld	19952	coprolite	pig	Very abundant burnt material, and fibres. Four starch granules (Fig. 12.1).
S3-2	54516	coprolite	pig	Small amount of burnt material, some fibres, one very small starch granule (2-3µm) (Fig. 12.5)
S3-4	54655	coprolite	dog/human	Very abundant burnt material
S3-5	51179	coprolite	ruminant?	Very abundant burnt material, plant fragments bordered pits. 2 starch granules
S3-10	54845	coprolite	dog/human	Plant fibres, no burnt material 1 starch granule (Fig. 12.2 and Fig. 12.3)
S3-11	54827	coprolite	not faecal	Plant fibres (bordered pits – xylem), some burnt material
S3-13	53814	coprolite	dog?	Small amount of burnt material, some fibres
S3-15	43716	coprolite	pig	One small starch granule (9µm), Plant fibres some burnt material
S3-18	54752	coprolite	n.d.	Very abundant burnt material, fibres (Fig. 12.4)
S3-20	57443	coprolite	human	Abundant burnt material, and plant fibres, some very long and thin
S3-28	54488	coprolite	human/ ruminant	Very little burnt material, some fibres
S4-1	1420	coprolite	n.d.	Abundant burnt material, plant fragments, bordered pits One starch granule
S4-4	629	coprolite	n.d.	No burnt material, plant fragments, bordered pits, and long thin fibres

310 Copeland & Hardy 2018.
311 Shillito *et al*. 2020a.
312 Polynesia, Horrocks *et al*. 2004; North-America, Reinhard *et al*. 2012; South-America, Vinton *et al*. 2009; Haas *et al*. 2013.

Table 12.2 Starch granules recovered from samples.

Coprolite code	Sample number	Producer (GC-MC)	(Group) shape	Size
S3-2	54516	pig	(1) very small	2-3µm
S3-15	43716	pig	(1) very small	9.09 µm
S3-5	51179	ruminant?	(2) lightly oval	42.41 µm
S3-5	51179	ruminant?	(2) lightly oval	26.48 µm
S3-10	54845	dog/human	(2) lightly oval	38.19 µm
S3-11	54827	not faecal	(2) lightly oval	58.25 µm
S4-1	1420	n.d.	(2) lightly oval	21.25 µm
Hardinxveld	19952	pig	(3) angular	12.58 µm
Hardinxveld	19952	pig	(3) angular	18.5 µm
Hardinxveld	19952	pig	(3) angular	17.3 µm
Hardinxveld	19952	pig	(3) angular	14.2 µm

12.3 Results

Eleven starch granules were recovered in total. Additionally, abundant carbonised material and plant fibres and xylem fragments, burnt and unburnt, were recovered in almost all of the samples.

12.4 Discussion

12.4.1 Starch granules

Eleven starch granules were recovered (Figs 12.1, 12.2 and 12.3). These fall clearly into three different groups; 1, very small; 2, medium sized and lightly oval; 3, small and angular. While it is not possible to determine the plant origin of these granules, the consistency within these groups suggests at least three different plant sources. It is notable that in the sample with most granules (Hardinxveld-Giessendam De Bruin 19952) all these were very similar in size and shape (3, small and angular) and were very different to all other granules (Fig. 12.1). This

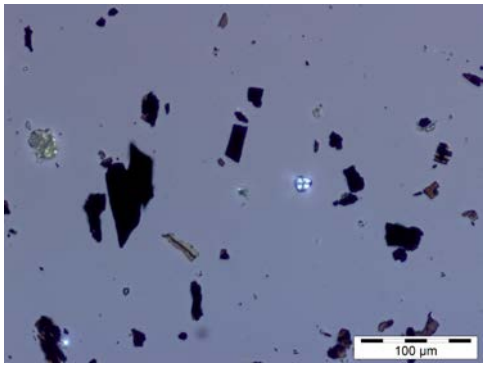


Figure 12.1 Angular starch granule and abundant burnt material (Hardinxveld 19952).

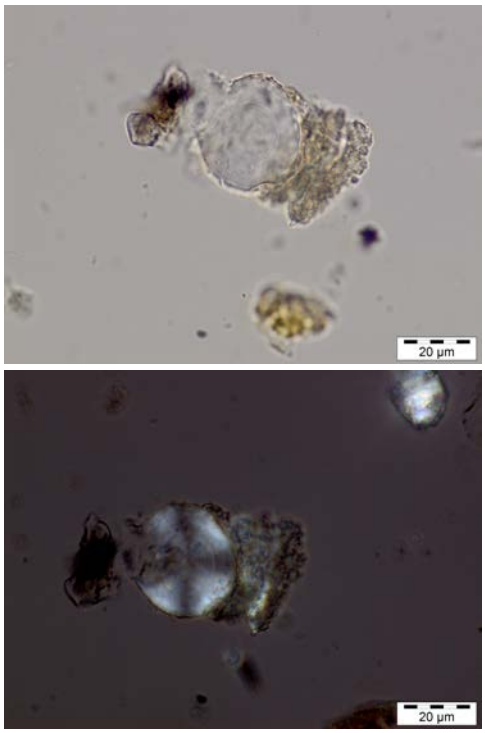


Figure 12.2 Starch granule (group 2), a. brightfield, showing growth rings; b. darkfield showing extinction cross (S3-10 54845).

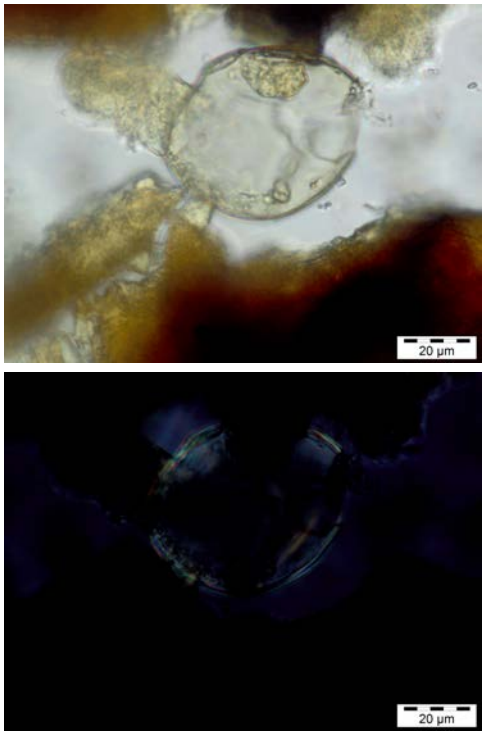


Figure 12.3 Starch granule (group 2), a. brightfield; b. darkfield (S3-10 54845).

strongly suggests that they represent one plant source that was ingested by the Hardinxveld-Giessendam individual, that is not identified in any other individual. The medium sized lightly oval granules (2) from Swifterbant-S3 (coprolite sample S3-10) are also consistent enough to suggest one plant source (Fig. 12.2 and 12.3). While they cannot be positively identified, they do not contradict the broad size and shape of water-lily (*Nymphaea* sp.) granules. The two very small granules (1) were too small to analyse in detail and their size is different enough that they may have come from different plant sources.

12.4.2 Why so few starches are found in coprolites.

In modern human diet, starchy food is generally cooked. When starchy food is cooked, the starch granules break down, in a process called gelatinisation. This aids digestion and increases energy productivity from the food eaten. Chewing gelatinised starch aids the digestive process due to the presence of an enzyme called amylase that is present in saliva and begins to break down the starches immediately when they are ingested. This starch digestion continues in the small intestine where pancreatic amylase completes the hydrolysation of starch to the component monosaccharides. If starch is ingested raw, much of it passes through to the colon where bacteria ferment the starch granules, sometimes causing pain and flatulence. A small number of resistant starch granules do not break down in the small intestine and pass through to the colon where they are generally broken down through fermentation. Therefore, the likelihood of starch granules surviving to reach a coprolite is very low.

12.4.3 Other material

Although very few starch granules were recovered, the presence of abundant fragments of burnt or carbonised material in most samples suggests cooked food. While small fragments of

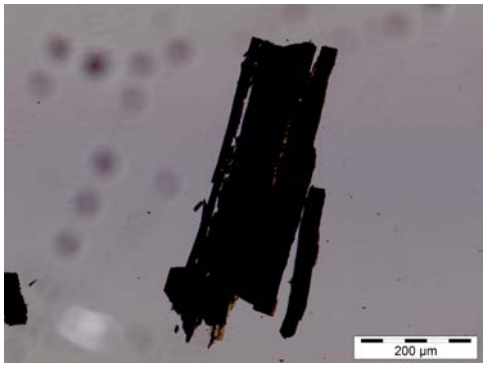


Figure 12.4 Large, carbonised fragment of likely herbaceous plant tissue embedded in the matrix of S3-18 coprolite.

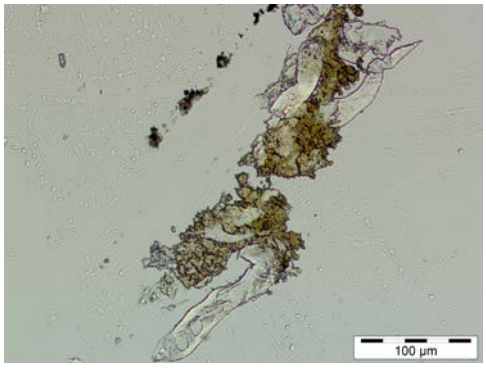


Figure 12.5 Likely plant fibre fragment embedded in the matrix of S3-2 coprolite.

carbonised material can be inhaled, in some samples the carbonised particles were very large. Likewise, it is unlikely that very large amounts of inhaled material would reach coprolites since the route for inhalation is primarily the lungs rather than the digestive system (Fig. 12.4). Xylem fibres are readily identifiable due to the lines of bordered pits in them. Most samples had uncarbonized fragments of xylem, suggesting most likely consumption of leaves, stems, bark, and/or tubers (Fig. 12.5).

13 Synthesis - Human versus community diet

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13.1 Introduction

The aim of this final chapter is to integrate the results obtained from the multi-disciplinary study applied to a series of coprolites from the Late Mesolithic and Early Neolithic Swifterbant Culture sites, to determine their role as a source of information about the prehistoric dietary tradition and health.

The study of coprolites provides a unique opportunity to reconstruct the most complete spectrum of the foods that were consumed in the past, both as cooked meals as well as foods that were eaten raw. In addition to the food remains, coprolites also contain intestinal parasites which affected the health of prehistoric populations. Coprolite studies can also provide information about palaeoenvironmental conditions through the types of microfossils and macrofossils they contain.

13.2 The project

The project 'Neolithic Human Diet Based on Studies of Coprolites from the Swifterbant Culture sites' was one in a series of studies referred to as Pre-Malta research. It was commissioned by the Cultural Heritage Agency of the Netherlands. BIAX Consult was honoured to take the lead in this project. It aimed to assess the diet and health of the Swifterbant populations through the analysis of coprolites from sites excavated before 2007. Four sites were selected, as they provided preservation of coprolites, including Hardinxveld-Giessendam De Bruin in the Lower Rhine-Meuse delta, and three sites in the province of Flevoland, including Swifterbant-S3 and -S4, and Emmeloord-J78-91 (the later site, however, was eliminated in the early stage of the project).

The first step in the project was to form a research team. We assembled a group of specialists from various countries to work together and contribute their highly sensitive research methods to the project. Multiple proxies were combined, including sterols and bile acids (together termed 'faecal steroids'), micro-CT scans, SEM images, animal bone remains, phytoliths, pollen, intestinal parasites and starch granules (see Table 13.1).

As with every project, this one also started on *Day* 1, on the 15th of July 2019 when the five coprolites recovered from Hardinxveld-Giessendam De Bruin were collected from the depot of the province of Zuid-Holland in Alphen aan den Rijn. Then, on the 22nd of July 2019 the coprolites recovered from the Swifterbant-S3 and -S4 sites and Emmeloord were collected from the archaeological depot of the province of Flevoland in Lelystad. It was beyond any expectation that as many as nearly 350 small paper bags with coprolites recovered from the S3 and S4 sites were stored in Lelystad archaeological depot.

13.3 The world of the Swifterbant Culture (c. 5000-3400 cal BC)

In the Netherlands, the Swifterbant sites were concentrated in two main areas: in the Lower Rhine-Meuse delta and the Swifterbant area in the province of Flevoland. The site of Hardinxveld-Giessendam De Bruin, located in the Lower Rhine-Meuse delta, witnessed the transition from the Late Mesolithic to the Early Swifterbant, while sites Swifterbant -S3 and S4 are dated to the classic Swifterbant Culture. The sites in the Swifterbant area were extensively excavated and studied, and only very recently was it concluded that the S3 and S4 sites would have functioned as one settlement in the Swifterbant period, perhaps only divided by a small creek. The neolithisation of the Swifterbant Culture is proposed as a long process that started around 5000 cal BC with the production of pottery, either invented or adopted. At around 4600 cal BC, there is some evidence that domesticated animals were incorporated into the Swifterbant economy. The introduction of small-scale cereal cultivation into the Swifterbant subsistence followed around 4300 cal BC and gradually gained more importance, but never seemed to become dominant before c. 4000 cal BC. The Mesolithic roots of the Swifterbant Culture are attested to in the reliance on hunting and fishing, and the gathering of wild plants for food. Perhaps the best way we could describe the economy of these people would be hunter-gatherers and farmers with an 'extended broad-spectrum economy'.[313]

[313] Louwe Kooijmans 2003; Raemaekers 1999; 2019.

13.4 Strategy for coprolite analysis

Although coprolites are generally a rarely encountered archaeological find, hundreds of coprolites were recovered at Swifterbant Culture sites as the result of suitable past burial conditions and the excavation methods. Only a fraction of these coprolites could be expected to be of human origin as coprolites produced by other omnivores such as pigs and dogs can be easily mistaken for human coprolites. As a result, the selection of the best coprolite candidates for detailed studies focusing on human diets cannot be guaranteed. The small size and heterogeneous nature of human coprolites render subsampling for a modern multi-disciplinary analysis very challenging. The fact that the least mineralised coprolites tend to crumble when they are manipulated while the most mineralised coprolites cannot be separated manually adds to the difficulty. The see-through (visually penetrating without damage) capacity of micro-CT can and should be exploited to outline the difficulties related to coprolite selection and subsampling for further study and to assess the representativeness of subsequent analyses. Coprolites containing only small bone fragments or bones without a specific shape can be deselected for zoological analysis. Plant tissues can be targeted during a scan-guided micro-extraction. The recovered tissues might then be identifiable at a very high taxonomic level using the SEM. One specimen could be selected for further analysis from a group of coprolites exhibiting similar scans. Micro-CT scanning can take place at the start with all of the other techniques to follow.

13.5 Integration of the multi-disciplinary evidence preserved in the coprolites

When we integrate the various lines of evidence and dietary components preserved in the studied coprolites, it seems that a more complete picture emerges for the individual coprolites (see Table 13.1). For example, the S3-2 coprolite shows a sausage-like shape with cracks on the surface (Appendix II, Plate IV). The determination of faecal steroids indicated human/pig as the producer organism. The plant component in this coprolite consisted of both emmer chaff and reed leaves and/or stems. Its internal matrix was also filled with both small and large fish bones, including vertebrae and teeth (some still embedded in the palate). The large chunks of fish bones in this coprolite, together with the large quantities of reed and other grasses (in phytolith remains) may speak in favour of the animal (likely pig) origin of this coprolite.

The S3-4 coprolite was defined based on faecal steroids as being of human/dog origin. Seeing the morphology of this coprolite, however, particularly its characteristic lumpy surface (Appendix II, Plate V) and the mainly small fish bone fragments (no vertebrae!) embedded in its matrix, one would argue for the human origin of this coprolite. The presence of a *Capillaria* egg suggests the consumption of infected meat (possibly freshwater fish). Numerous silicified epidermal tissue fragments from emmer chaff (lemma or palea) in the SEM images and the phytoliths of cereal husks (both *Triticum* and *Hordeum*) indicate cereals as a meal component. Charred emmer chaff epidermal tissue was found in the pollen slides as well. Leaf epidermal fragments of *Polygonum aviculare* embedded in the coprolite matrix suggest that the leaves of knotgrass were part of the meal.

In the assessment phase of the faecal steroids, it was suggested that coprolite S3-28 was of human origin. In the final analysis, however, human/ruminant origin was considered as the producer organism. The morphological appearance of S3-28 (Appendix II, Plate XIX, separated hard lumps) and the internal contents of this coprolite could speak in favour of human origin. Remains of silicified epidermal tissue from emmer chaff (lemma or palea) in the SEM images, accompanied by apple and white water-lily seeds and fine pike and perch bones, could all be interpreted as remains of a meal (or meals) consumed by a human rather than by a ruminant. Charred emmer chaff epidermis was also found in the pollen slides. Furthermore, coprolite S3-28 contains the highest concentration of intestinal parasite eggs; in particular, many eggs of whipworm (*Trichuris*) are present. Based on the size of these eggs it can be deduced that these probably belong to *Trichuris trichiura*, which has humans as hosts, but another possibility is that the eggs are *T. suis*,

which has pigs as hosts. In addition, eggs of fish tapeworms (Diphyllobotriidae) and flukes (Opisthorchiidae) were found, indicating the consumption of freshwater fish. The composition of intestinal parasites therefore also points to human origin rather than ruminant.

The S3-10 coprolite was defined, based on faecal steroids, as being of dog/human origin. The pericarp tissue of likely barley (*Hordeum*) (on pollen side) offers a piece of strong evidence for the consumption of grain by the individual associated with this coprolite. The pollen assemblage and the composition of the intestinal parasites of S3-10 much resemble that of S3-11. Also, the morphologies of both S3-10 and S3-11 are very much alike, suggesting similar producers (see Appendix II, Plate VIII, and IX). In S3-11 charred emmer chaff epidermal tissue was found on the pollen slides as well. *Trichuris* eggs in both coprolites may point to a human (or pig) origin rather than a dog. The presence of a barbule in S3-10 and hair of likely red deer in S3-11 suggest the consumption of meat or the processing of animal products. White water-lily seeds were the dominant component in those two coprolites (S3-10 and S3-11). The overwhelming presence of the seeds throughout the matrices of both coprolites is well illustrated in the micro-CT scans. It is clear from these images that the seeds were the main component of the meal, consumed, possibly, with the addition of fish, as suggested by the fish bones and fish scales that accompanied the water-lily seeds. Usually, the testa of the empty seeds was preserved, often deformed but still revealing the outline of the individual seeds. Also, many seed fragments were embedded in both coprolite matrices. In S3-20 (human coprolite) and S3-28 (likely-human coprolite), the white water-lily seeds were also present, but were represented only by a few seed remains embedded in the coprolite matrices. In S3-11, as well as in S3-28 and S4-1, marsh mallow (*Althaea officinalis*) pollen suggests the consumption/use of this edible and medicinal plant (mild laxative and gentle purgative properties).

Fragments of silicified epidermal tissue from emmer chaff were detected in the SEM images from the S4-1 coprolite. Charred emmer chaff epidermis was found in the pollen slides. This coprolite revealed a very fragile and deteriorated internal structure (also shown in the micro-CT scan), very different from most of the S3 and S4 coprolites which were often hard and solid. Many small fish bones (including vertebrae) were present within the crumbling matrix of the S4-1 coprolite. Also, large quantities of melted silica were found in phytolith assemblages from this coprolite. One would wonder if the melted silica could actually be melted phytoliths, possibly representing the results of cooking for long times at high temperatures. This assumption is supported by finds of melted phytoliths that have been recovered in archaeological settings.[314] Coprolite S4-1 was indicated as being of human origin in the assessment phase of its faecal origin. However, this brief determination was not confirmed in the final analysis as no human faecal steroids were detected. The morphological appearance of this coprolite (a sausage shape with cracks on the surface, Appendix II, Plate XXI), its great similarity to S3-20 (human coprolite; contains *Triticum* grain pericarp tissue), and the food components found in its matrix suggest that it may well have originated from a human source. As already mentioned above, *Trichuris* eggs were also found in coprolite S4-1, suggesting a human origin. In addition, an egg of kidney worm (*Dioctophyma*) was present. Kidney worm has dogs as well as humans as final hosts. The indication for the consumption of freshwater fish is strengthened by the presence of Opistorchiidae (fluke) eggs. The composition of the intestinal parasite eggs of S4-4 suggests a similar origin as that of S4-1.

Five of the studied coprolites (S3-4, S3-5, S3-13, S3-18 and S3-20) share the presence of what are likely to have been knotgrass leaves. One of these coprolites (S3-20) (Appendix II, Plate XV) was defined as human in the faecal steroid analysis. This coprolite also contains remains of white water-lily seeds and fish and mammal bones. In addition, phytoliths of cereal husk (likely barley) were found in the matrix of this coprolite. In the assessment phase of the faecal steroid study, coprolite S3-18 was suggested to be likely a human/pig coprolite. Its definitive status, however, was not resolved as the biomarkers for faecal steroids were extremely low. Besides knotgrass leaves, this coprolite also contains phytoliths of cereal husk (likely barley) and fish remains (numerous tooth remains of pike). Judging by the morphological appearance of this coprolite (significant for

[314] Scott Cummings, personal communication.

human coprolites: sausage shape and lumpy/wrinkled surface; Appendix II, Plate XIII) and the fine internal matrix, human origin may be likely here. Two other coprolites with knotgrass leaf remains are likely of ruminant (S3-5) and carnivore/dog (S3-13) origin (Appendix II, Plates VI and XI, respectively). In addition to knotgrass leaves, coprolite S3-5 showed evidence both of silicified emmer chaff epidermis in the SEM images and phytolith microfossils of cereal husks (both *Triticum* and *Hordeum*). Also, numerous reed leaf/stem phytoliths and silicified epidermal tissue of reed stems (in the SEM images) were identified in this coprolite. Fish teeth and vertebrae accompanied the plant remains.

Coprolite S3-13 originated from a carnivore, likely a dog. This coprolite has an intriguingly smooth surface (Appendix II, Plate XI). Its morphological appearance seems to match its

Table 13.1 The combined results of various analyses applied in this study.

Coprolite code	Sample number	Charred particles emeded in coprolite matrices, observed during subsampling for microfossil anayses	Macroremains in residues from pollen preparations	Faecal steroids (1-assessment phase, 2-analysis phase, 3-revised)	Bone remains	micro CT-scan
Hardinxveld	19520	few Phragmites stem particles	.	1. indicates poor preservation so unable to determine source organism-2. not confirmed as faecal	perch (dentale, scale); fish indet.; mammal, indet.	perch dentale and scale; indet. Charred plant tissues?
Hardinxveld	19952	few small charcoal fragments, also few Phragmites stem particles	charred herbaceous particles	1. likely pig-2. pig	perch (vertebra, spine, scale); duck bone; mammal, indet.	fish scales, vertebras, finray; indet. Charred plant tissues?
S3-2	54516	numerous likely Phragmites stem particles	charred herbaceous particles	1. human – 2. pig	pike (vertebra, tooth, palatinum); fish indet.	fish vertebras, palatinum, pike teeth; fish indet. Charred plant tissues?
S3-4	54655	numerous Phragmites stem particles	charred herbaceous particles	1. human-2. human-3. dog/human	fish, indet.	fishteeth, scales; indet. Indent. voids, possibly plant phantoms, many elongated, one sub-spherical, one stick-like
S3-5	51179	few reed stem particles	charred Phragmites stem particles	1. unlikely human, bile acids suggest most likely ruminant-2. ruminant?	pike (vertebra, tooth, spine); fish indet.	fish vertebras and teeth, fish indet. Many thin elongated voids, some large stem like plant voids
S3-8	53985	some large fragments of Phragmites stem, incl. nodium remains	.	1. indicates poor preservation so unable to determine source organism-2. pig	perch (vertebra, articulare, scale); fish indet.	"perch (vertebras, many with spines and scales), detached spines; indet. Many thin elongated voids and several large voids with distinct shape, possibly phantoms of rolled tissues, platy tissues with ribs and rounded seed fragment"

faecal steroid profile very well, both taken together suggesting a dog origin. Besides the knotgrass leaves, there are also cereal husk phytoliths (likely both wheat and barley) and numerous reed leaf/stem phytoliths.

We can conclude that knotgrass leaves were found in one human and one likely-human coprolite (S3-20 and S3-18, respectively), and in two animal coprolites, one of which is of ruminant origin (cattle and/or sheep/goat) and the other likely derived from a dog (S3-5 and S3-13, respectively). This indicates that the leaves of knotweed were consumed by people living on the S3 settlement, likely as green/leaf vegetables. The leaves and probably the complete young plants must also have been eaten by domestic animals wandering freely through the settlement.

SEM	Phytolith qual assessment	phytolith counts (for cereal husk & Phragmites)	Pollen and other microfossils	Helminths	Starch granules (Group) shape
herbaceous stem tissue (possibly grass)	no data	no data	no data	no data	no data
likely Phragmites stem epidermis with long cells accompanied by gramineous type stomata and few papillae	no phytoliths, some minerals	no phytholits	Alnus, Artemisia, Chenopodiaceae, Filipendula, Nymphaea seed testa fragment, likely apple epidermis/ parenchyma, Foraminifera, fine wool	97 eggs/ml: 97 trematode eggs > 86 µm	(3) angular, four starch granules (12.58 µm, 18.5 µm, 17.3 µm, 14.2 µm)
silicified epidermal tissue likely of emmer chaff acompanied by numerous papillae/trichome scars; epidermal surface, likely from emmer glumes, showing numerous papillae accompanied by gramineous-type stomata; numerous fragments of herbaceous leaves/stems (includind some parenchyma)	large quantity of highly silicifed, large conjoined reeds, grasses	reed leaf/stem 116x	no pollen, only charred plant remains including cf. Cereal epidermis	no data	(1) very small starch granule (2-3µm)
silicified epidermal tissue from emmer chaff (lemma or palea); Phragmites leaf (epidermal tissue); herbaceous leaf fragments (indet.), leaf fragments of cf. Polygonum aviculare	lots of reeds etc but seem to be more fragmented. More noticeable number of shirt cells than others	Cereal husk ?Triticum 3x, Cereal husk ?Hordeum 1x, reed leaf/stem 120x	very poor in pollen, Cerealia pollen, , Chenopodiaceae, Typha angustifolia, T. dicoccum, epidermis (C)	14 eggs/ml: Capillaria sp.	no starch granules
silicified emmer husks (imprints of epidermal cells), silicified epidermal tissue-likely Phragmites stem (culm) with numerous papillae and gramineous type stomata (the same tissue as in S3-2), herbaceous leaf fragments (cf. Polygonum aviculare - the same tissue as in S3-13 and S3-18)	large quantity of highly silicifed, large conjoined reeds, grasses	Cereal husk ?Triticum 2x, Cereal husk ?Hordeum 3x, reed leaf/stem 153x	Artemisia, Humulus, likely apple epidermis/ parenchyma	no data	(2) lightly oval, two starch granules (42.41 µm and 26.48 µm)
leaf remains of Viscum album with epidermal tissue and stomata (the same tissue as in S4-4); herbaceous leaf fragments with trichomes and trichome scars (the same tissue as in S4-4)	no data	no data	no data	no data	no data

Coprolite code	Sample number	Charred particles emeded in coprolite matrices, observed during subsampling for microfossil anayses	Macroremains in residues from pollen preparations	Faecal steroids (1-assessment phase, 2-analysis phase, 3-revised)	Bone remains	micro CT-scan
S3-10	54845	few herbaceous particles	Nymphaea alba-seed testa fragments, charred herbaceous particles	1. human-2. human-3. dog/ human	pike (vertebra), cyprinid (vertebra, spine); fish indet.	distal finray, vertebras and scales, indet. Numerous water-lily seeds, one phantom of apple seed plus a few large unidentified tissues or voids.
S3-11	54827	.	Nymphaea alba-seed testa fragments	1. indicates poor preservation so unable to determine source organism-2. not confirmed as faecal	.	fish vertebras and indet. Numerous water-lily seeds.
S3-12	53842	numerous Phragmites stem fragments & small herbaceous particles	.	1. indicates poor preservation so unable to determine source organism-2. not confirmed as faecal	fish, indet.++	.
S3-13	53814	some large fragments of Phragmites stem	charred herbaceous particles	1. indicates poor preservation so unable to determine source organism-2. unknown source-3. unknown, possible carnivore	.	fish vertebras, fish jaw bone; indet. Long rolled plant tissue (leaf?).
S3-15	43716	some fragments of Phragmites stem	charred herbaceous particles	1. likely human-2. pig	pike (vertebra, spine); fish indet.	fish vertebras ,spines, scales, fin; indet. One large spherical plant phantom (?)
S3-18	54752	some fragments of Phragmites stem	few charred herbaceous particles	1. 'likely human and have good concentrations' in first round, while in second attempt 'likely pig', 2. in final results - n.d. faecal steroids not detected	pike (vertebra); fish indet.	fish vertebras, scales, pike teeth; indet. Long rolled tissues (leaf?); possibly Cereal chaff
S3-20	57443	some fragments of Phragmites stem	charred herbaceous particles	1. human-2. human	pike (vertebra, tooth, quadratum, spine); cyprinid (vertebra); fish indet.; mammal, indet.	fish vertebras, at least one cyprinid vertebra, pike teeth; indent. One water-lily phantom.
S3-26	53954	fragment of reed stem(?) embedded in the matrix	.	1. indicates poor preservation so unable to determine source organism-2. human-3. dog/ human	pike (vertebra), perch (vertebra, scale); fish indet.	fish vertebras, at least one pike vertebra, scales, fish skulls; indent. Phantoms of seeds (tri-facet seed and water-lily)
S3-28	54488	some small fragments, possibly Phragmites stem, also other herbaceous particles	charcoal particles	1. human-2. unknown (human/ruminant)	pike (vertebra), perch (scale), fish indet.	perch (scale), vertebras, fin; indet. Phantoms of apple seeds

SEM	Phytolith qual assessment	phytolith counts (for cereal husk & Phragmites)	Pollen and other microfossils	Helminths	Starch granules (Group) shape
numerous seeds of white water-lily (Nymphaea alba)	large quantity of phytoliths, fragmented and broken, brown staining	Cereal husk ?Triticum 1x, Cereal husk ?Hordeum 2x, reed leaf/stem 7x	Cerealia pollen, cereal pericarp likely Hordeum, Polygonum aviculare-type, Lathyrus-type, cf. Rubus, Filipendula cf. vulgaris, Mentha-type, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Nymphaea, likely apple epidermis/parenchyma, Nymphaea seed testa fragments ++++, feather barbule	1103 eggs/ml: Trichuris trichiuria(-suis); Diphyllobotrium; Diphyllobotriidae	(2) lightly oval, one starch granule (38.19 µm)
numerous seeds of white water-lily (Nymphaea alba)	few, digested, grasses	reed leaf/stem 11x	Lathyrus-type, Filipendula, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Althaea officinalis, Nymphaea, likely apple epidermis/parenchyma, Nymhaea seed testa frag +++, cf. cereal pericarp (c), cf. T. dicoccum epidermis chaff , hair likely red deer	1396 eggs/ml: Trichuris trichiura(-suis); Diphyllobotrium; Diphyllobotriidae; Opistorchiidae	(2) lightly oval starch granule (58.25 µm)
herbaceous stem/leaf tissue; possible parenchyma cells, indet.	no data	no data	no data	no data	no data
numerous leaf fragments of cf. Polygonum aviculare, rolled (the same tissue as in S3-5, S3-18, S3-20)	large quantity, highly silicifed,	Cereal husk ?Triticum 1x, Cereal husk ?Hordeum 1x, Reed leaf/stem 180x	hardly any pollen, Poaceae, Matricaria-type, cf. Cereal epidermis (c), likely apple epidermis/ parenchyma, fine wool	27 eggs/ml: Trichuris trichiura(-suis)	no starch granules
silicified epidermal tissue, likely of Phragmites stem (culm); indet. herbaceous leaf/stem	large quantity of highly silicifed, large conjoined reeds, grasses. Very clean sample.	Cereal husk ?Triticum 2x, Cereal husk ?Hordeum 2x, reed leaf/stem 85x	Artemisia, Typha angustifolia, Chenopodiaceae, likely apple epidermis/ parenchyma, fine wool	no data	(1) very small starch granule (9µm)
leaf fragments of cf. Polygonum aviculare (the same tissue as in S3-5, S3-13, S3-20)	large quantity of highly silicifed, large conjoined reeds, grasses, charcoal. Very clean.	Cereal husk ?Hordeum 6x, reed leaf/stem 156x	very poor in pollen, Alnus, Poacaea, epidermis T. cf. dicoccum chaff	no data	no starch granules
white water-lily (Nymphaea alba), leaf fragments of cf. Polygonum aviculare (the same tissue as in S3-5, S3-13 and S3-18); indet. herbaceous stem/ leaf tissue	large quantity of highly silicifed, large conjoined reeds, grasses, husks? Very clean.	Cereal husk ?Hordeum 2x, reed leaf/stem 99x	Filipendula cf. vulgaris, Chenopodiaceae, cereal pericarp likely T. dicoccum (c)	no data	no starch granules
herbaceous stem/leaf tissue, indet.; diatoms	no data	no data	no data	no data	no data
silicified epidermal tissue-likely emmer chaff epidermis, crab apple (Malus sylvestris) and white water-lily (Nymphaea alba) seeds; diatoms	large quantity, highly fragmented, some eroded, brown staining	reed leaf/stem 50x	Cerealia, Artemisia, Rosaceae cf. Rubus, Filipendula cf. vulgaris, Mentha-type, Solanum dulcamara, Typha latifolia, Chenopodiaceae, Althaea officinalis, Nymphaea, Nymphaea seed testa fragments +, cf. apple epidermis, T. cf. dicoccum epidermis chaff (c), cf. cereal pericarp (c)	3880 eggs/ml: Trichuris trichiura(-suis); cf. Diphyllobotrium; Opistorchiidae	no starch granules

Coprolite code	Sample number	Charred particles emeded in coprolite matrices, observed during subsampling for microfossil anayses	Macroremains in residues from pollen preparations	Faecal steroids (1-assessment phase, 2-analysis phase, 3-revised)	Bone remains	micro CT-scan
S4-1	1420	few herbaceous particles	charred herbaceous particles	1. human-2. n.d. = faecal steroids not detected	pike (vertebra); fish indet.	fish vertebras; indet.
S4-4	629	few herbaceous particles	herbaceous particles	1. likely human-2. n.d. = faecal steroids not detected	.	spongious fish bones?

13.6 Answering the research questions

For this project, our focus was mainly concerned with the dietary diversity and preparation of food in the Swifterbant tradition, with attention to both plant and animal components. The evidence for the consumption of plant foods in general, and cereals in particular, was of great interest. Also, the health conditions of the Swifterbant people were studied in terms of the presence of intestinal parasites. During our research, we encountered a large amount of plant and animal remains. The observed taxa of the Swifterbant coprolites are summerised in Appendix XIII. In the following sections the research questions which were formulated at the start of the project are answered in a summarizing way:

1. Who or what was the producer of the coprolites? See Section 13.7;
2. What were the Swifterbant peoples' typical meals? See Sections 13.8 and 13.9;
3. How much cereal did they eat? See Section 13.8;
4. Can the crucial dietary shift, the introduction of cereals to the Swifterbant diet, be identified and evaluated more accurately? See Sections 13.8 and 13.14;
5. What natural environment did the Swifterbant people live in? See Sections 13.10 and 13.11;
6. What can be said about seasonality? See Section 13.12;
7. What were the health conditions of the Swifterbant populations? See Section 13.13;
8. NOaA 2.0 question 7: How did the way of life change during the Late Mesolithic until the Late Neolithic? See Section 13.14;
9. NOaA 2.0 question 8: Which landscape zones were used in the Late Mesolithic and Early Neolithic for habitation, hunting, arable farming and livestock? See Section 13.15;
10. NOaA 2.0 question 22: What role did the exploitation of natural food resources play after the introduction of agriculture? See Section 13.16.

13.7 Faecal biomarker results and coprolite origins

In archaeological studies, the coprolites of human origin and the domesticated animals associated with them are usually of great interest. It was not different in this project, except that with this project the primary focus was to be on human coprolites. Human faecal remains are often difficult to identify with certainty. In particular, distinguishing human from dog coprolites can be challenging because they are often similar in size and shape, and they tend to occur together at archaeological sites.

There are several methods available to and applied in coprolite analysis that help to define their faecal origin, each with its advantages and limitations. aDNA and GC-MS are the most commonly used. The method used in this project

SEM	Phytolith qual assessment	phytolith counts (for cereal husk & Phragmites)	Pollen and other microfossils	Helminths	Starch granules (Group) shape
silicified epidermal tissue from emmer chaff (lemma or palea); Phragmites leaf (epidermal tissue with gramineous type stomata)	lots of melted silica, large quantity silicifed phytoliths, some appear eroded, staining	reed leaf/stem 87x	Cerealia pollen, Artemisia, Filipendula cf. vulgaris, Solanum dulcamara, Typha angustifolia, Chenopodiaceae, Althaea officinalis, Nymphaea seed testa (v), likely apple epidermis/parenchyma, epidermis cf. Triticum cf. dicoccum (c)	54 eggs/ml Dioctophyma sp; Trichuris trichiura(-suis); Opistorchiidae	(2) lightly oval starch granule (21.25 µm)
leaf remains of Viscum album with epidermal cells and multiple stomata (the same tissue as in S3-8); indet. herbaceous leaf fragments with trichomes and trichome scars	very few, digested, grasses	no cereals, no Phragmites	very poor in pollen, Poacaea, Lemnaceae, Armeria/Limonium, Nymphaea, cf. cereal epidermis	282 eggs/ml: Dioctophyma sp.; Trichuris trichiura(-suis); Opistorchiidae	no starch granules

to help to identify the producer organism for 25 of the selected coprolites was GC-MS (gas chromatography mass spectrometry). With this method, the sterol and bile acid fractions in the coprolites were analysed.

Faecal lipid biomarkers (steroid compounds) have been used as diagnostic tools to identify the producer organisms of coprolitic deposits across a range of environmental and temporal settings, successfully discriminating between herbivore, carnivore, porcine, and human sources.[315] Species-specific coprolitic identification requires a combination of the analysis of sterol compounds, the characterising of major dietary profiles, and the identification of bile acids to facilitate inter-species discrimination.

The identification of the coprolitic source organisms in this study has, however, been limited by low concentrations of both sterols and bile acids in the majority of the samples, which either precluded source identification or presented multiple possible source organisms. In some coprolites, the low steroid concentration could not even confirm that the samples were of faecal origin. No steroids detected does not necessarily mean 'not of faecal origin' - but it could not be proved using the lipids. This technique will likely have different outcomes when used to distinguish human from non-human coprolites in drier environments since sterols and bile acids contain a region that is water soluble.

According to the GC-MS assessment of the initial lipid extractions, there were some traces of possible bile acid compounds in several of the samples, suggesting a human or likely-human origin for eight coprolites and an animal origin for three (including two pigs and one ruminant). The concentrations of lipids in 14 coprolites were too low to enable the determination of the source organisms. Due to time constraints, we had to use the tentative source identifications that were available to allow other multi-proxy analyses to be completed as part of this project, while we continued to extract and analyse more lipids from additional sample material. Unfortunately, even with this additional material, the concentrations from the combined extracts were too low to detect sufficient bile acid compound concentrations in many of the samples by GC-MS analysis, thus explaining the number of coprolites that were finally attributed to an unconfirmed source. Even though the samples were run twice, and while some were initially classified as a 'best fit' for human origin on the assessment run, the sterol and bile acid concentrations were too low to give a firm species identification in the analysis phase. Therefore, the lipid data/ratio calculations should be treated with caution. However, given the results from the multi-proxy analyses, the combination of data strongly suggests a human origin for many of the studied coprolites.

What was clear from the biomolecular analysis was that animal coprolites were present in the Hardinxveld-Giessendam De Bruin assemblage, and that both human and animal coprolites were represented in the assemblages from both of the S3 and S4 sites. The faecal

[315] Bull *et al.* 2002.

origin of the Emmeloord-J78-91 coprolites could not be specified. The summary of coprolite likely-producer-organisms based on faecal steroid analyses suggests that pigs, humans, and carnivores (likely dogs) were the dominant producer organisms of the confirmed coprolites, accounting for ten of the 25 analysed coprolite samples. Unfortunately, many of the coprolites presented multiple possible source organisms.

The first set of results, referred to as initial runs, was often confirmed in the final analyses, but some differed, and for these identifications, some explanations are proposed. For example, S3-2 was initially identified as a human coprolite, but in the final analysis as a pig. A possible explanation can be that Ratio 3 is 0.4, which is on the borderline for pigs (since ratios <0.4 signify pigs). Human ratios are usually 0.6+ and that is why this coprolite was attributed to a pig in the final analysis, but it is at the upper limit of the identification. The S3-15 coprolite was initially assessed as 'likely human,' but in the final analysis as a pig coprolite. Two other coprolites, S4-1 and S4-4, were assessed in the initial run as likely human; however, in the final analysis faecal steroids were not detected in those coprolites. The same occurred with S3-18, which in the initial run was defined as a likely pig coprolite, but did not yield any faecal steroid signature in the final analysis. The explanation, perhaps, of the discrepancy between the assessment runs and the analysis phase, lies in the possibility that different portions of coprolites were provided for each phase. Given the problems with low concentrations of faecal sterols, it might be more appropriate to assess this qualitatively using combined data.

Other studies have also reported examples of coprolitic samples that yielded inconclusive results, attributed to low faecal lipid preservation and the presence of multiple source organisms. The distribution of faecal biomarkers indicative of a mixed human/carnivore origin, for example, is explained by the coprophagy of human faeces by carnivores.[316] Coprophagy in canids (particularly in dogs) is a well-recognised phenomenon and could explain the presence of both carnivore-derived lipids and human biomarkers in some coprolites. The presence of coprolites with a dog/human faecal signature (possibly dog coprolites with a human element) in the coprolite assemblage studied in this project may possibly be explained by dogs eating human faecal remains. Future lipid work should adapt the methods to account for low concentrations and the fact that these are discrete coprolites rather than dispersed sediment samples.[317]

Before subsampling the coprolites for SEM and various microfossil analyses, the morphology of 16 coprolites was digitally documented. Their internal content was also documented in the form of micro-CT scans. We concluded that even though we could agree on the composition of the food remains within individual coprolites (plant versus animal food), we could not absolutely determine, based on the micro-CT scans, whether the producers of the studied coprolites were humans, dogs or pigs.

13.8 The plant component in the diet of the Swifterbant Culture

13.8.1 Cereals

Some of the research questions of the project were related to the consumption of cereals, as we wanted to know how much cereal the Swifterbant people ate and whether or not we could more accurately identify and evaluate the crucial dietary shift: the introduction of cereals into the Swifterbant diet. We definitely can present multiple lines of evidence for the consumption of the cereals at the Swifterbant sites in Flevoland (see Table 13.2). However, no evidence for cereal consumption was found in the coprolites from Hardinxveld-Giessendam De Bruin (Late Mesolithic-Early Neolithic).

The evidence for the presence of cereals is found in phytolith remains. The phytoliths of *Hordeum* (barley) husk were indicated in coprolites S3-18 and S3-20, and both *Hordeum* and *Triticum* (likely emmer) husks were represented in the phytolith assemblages from S4-4, S3-5, S3-10, S3-13 and S3-15. While these were only present in small numbers, this would be expected if cereals were de-husked as part of the preparation process (in the case of emmer) or entered the cooking pots as clean grain (in the case of naked barley). The few emmer and barley husks that were present were very well silicified, indicating that they were formed under conditions of high water availability and silica-

[316] e.g. Shillito *et al.* 2020b.
[317] e.g. as in Shillito *et al.* 2020a.

Table 13.2 Overview of cereal remains and other monocotyledons found in the Swifterbant coprolites.

Sample		Hardinxveld 19952	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
GC-MS (producer)		pig	pig	dog/human	?ruminant	dog/human	n.d.	?dog	pig	n.d.	human	human/ ruminant	n.d.	n.d.
Cereals:														
Cerealia husk (likely emmer)	phytoliths	.	.	3	2	1	.	1	2	.	.	.	.	.
Cerealia husk (likely barley)	phytoliths	.	.	1	3	2	.	1	2	6	2	.	.	.
Triticum dicoccon (emmer), chaff (lemma, palea, and/or glumes)	SEM	.	+	+	+	.	.	.	.	.	.	+	+	.
Cerealia-type, pollen	pollen & intestinal parasite slides	.	.	1	.	4	.	.	.	.	.	9	2	.
Cerealia-type?	pollen & intestinal parasite slides	.	.	.	.	.	.	.	.	.	.	5	.	.
Charred epidermis cf. Cerealia	pollen & intestinal parasite slides	.	+	.	.	.	.	+	.	.	.	.	.	.
Triticum cf. dicoccum, charred epidermis	pollen & intestinal parasite slides	.	.	+	.	.	+	.	.	+	.	+	+	.
Cerealia, pericarp (likely emmer)	pollen & intestinal parasite slides	.	.	.	.	.	.	.	.	.	+	.	.	.
Cerealia, pericarp (likely barley)	pollen & intestinal parasite slides	.	.	.	.	+	.	.	.	.	.	.	.	.
Monocots:														
Phragmites leaf/stem	phytoliths	.	116	120	153	70	11	180	85	156	99	50	87	.
Phragmites stem epidermis	SEM	+	.	.	+	.	.	.	.	.	.	.	.	.
Phragmites leaf epidermis	SEM	.	.	+	.	.	.	.	.	.	.	.	+	.
Monocot leaf/stem	phytoliths	.	100	70	23	110	5	42	56	125	103	46	86	2
Monocot husk	phytoliths	.	2	4	1	.	.	2	.	10	5	1	4	.
Charred epidermis Poaceae/Cyperaceae	pollen & intestinal parasite slides	+	+++	+	+	+++	++	++	+++	++	++	+	+	+
Charred epidermis Poaceae/Cyperaceae with stomata	pollen & intestinal parasite slides	+	++	+	.	.	++	+	+++	+++	++	+	+	+
Charred epidermis, Cyperaceae	pollen & intestinal parasite slides	.	++	+	.	.	.	+	++	+	+	.	.	+
Charred epidermis cf. Phragmites	pollen & intestinal parasite slides	.	.	.	+	.	+	+	+	.	.	.	+	+

rich substrate. These conditions likely favoured the preservation of phytoliths in general. The phytoliths embedded in coprolite matrices were exceptionally well preserved and were present in large quantities, which is not often the case in coprolites. The SEM images also demonstrated cereal components in five coprolites (S3-2, S3-4, S3-5, S3-28 and S4-1). The cereal tissue embedded in the matrices of these coprolites was assigned to the epidermal tissue of emmer light chaff (husks), which would have survived the de-husking process and, possibly still attached to the grain, entered the cooking pots. The waste from threshing cereals, if scattered

through the Swifterbant settlement, could also have been eaten by animals (dogs and pigs in particular) scavenging around the food preparation areas or it was deliberately fed to the animals. The evidence for the consumption of cereals was also detected on pollen and intestinal parasite slides. Interestingly, on some of the microscopic slides from S3-10 and S3-20, fragments of cereal pericarp (also referred to as bran) from resp. *Hordeum* (barley) and *Triticum* (likely emmer) grain were found. The grain pericarp tissues embedded in coprolite matrices offer the best possible evidence for the consumption of cereals.

The evidence for the consumption of cereals is omnipresent. It comes from different proxies, including SEM, phytoliths, pollen and intestinal parasite samples. Cereals - emmer and barley - were likely used as an addition to other foods and were eaten together with other foods. From studies on food crusts preserved on pottery from Swifterbant -S3 and -S4 sites, we know that both emmer and barley were cooked as a porridge-like food, sometimes with the addition of fish or green vegetables.[318] This composition of ingredients is now mirrored in the coprolites.

13.8.2 Green vegetables

Also exceptional were the large quantities of reed (*Phragmites*) phytoliths, representing both leaves and stems of this marsh plant. The silicified epidermal remains of reed were also indicated in the SEM analysis. Both reed phytoliths and their presence in the SEM images are good direct indicators that reed (probably young reed shoots) were eaten. Usually, it is difficult to distinguish whether these had been consumed, or if they derived from fuel or craft activity, but their presence in coprolites is a clear indicator of consumption, likely by both humans and animals.

Even though leaf or stem tissues of herbaceous plants are occasionally found in charred food crusts on ceramics and, as such, they indicate that green vegetables were cooked, a much larger variety of plants and their green parts would have been eaten raw. In five of the studied coprolites, leaf remains of likely knotgrass (*Polygonum aviculare*) were preserved as rolled or scroll-like fragments embedded in coprolite matrices (well observed in SEM images and micro-CT scans). The knotgrass leaves would have likely been used by people as leaf vegetables. The leaves, and perhaps the complete young plants, must also have been eaten by domestic animals. Knotgrass also has medical properties. It can be used for the treatment of parasitic diseases because of its laxative effect.[319]

Interestingly, two coprolites, S3-8 (pig) and S4-4 (likely human/no definitive origin of faecal steroids) revealed the presence of mistletoe (*Viscum album*) leaves embedded in their matrices. The leaves of mistletoe were also found earlier in animal dung at Neolithic wetland settlements in Germany (Alleshausen) and Switzerland (Arbon Bleiche 3) where it has been suggested that animals (cattle) were fed the evergreen leaves and stems of mistletoe. Obviously, in the Swifterbant tradition, the pigs were also fed mistletoe greens. If the animal dung from the S3 and S4 sites (which is now stored in the archaeological depot in Lelystad) were at some later point analysed, the issue of animal fodder and animal husbandry, in general, could be presented in a much broader sense. The possibility that mistletoe was used as a medicinal plant during the Swifterbant period cannot be completely excluded. At the same site of Arbon Bleiche 3, ivy (*Hedera helix*) leaves were also suggested as having been used as animal fodder. In the natural deposits from Hardinxveld-Giessendam De Bruin, *Hedera* pollen was present in high quantities. In one of the coprolites of Hardinxveld Giessendam De Bruin, the ivy pollen was also found. At Swifterbant, a pollen grain of *Hedera helix* is present (S3-15), but no leaf tissue could be identified.

13.8.3 Wild seeds, fruits and berries

It seems that seeds of water-lily were appropriated in Swifterbant tradition as the source of food. Two of the studied coprolites, S-10 and S11 revealed large amount of white water-lily seeds embedded in their matrices. One of the micro-CT scans provides the best picture for how densely coprolite S3-10 is packed with the remains of white water-lily seeds

[318] Raemaekers, Kubiak-Martens & Oudemans 2013.
[319] Chiej 1984; 242.

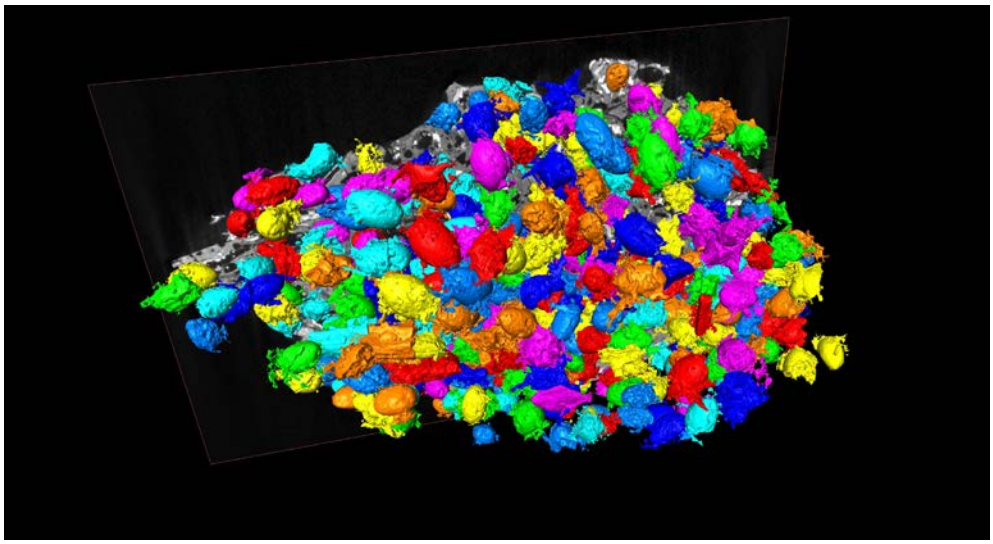

Figure 13. 1 Micro-CT scan showing white water-lily seeds embedded in the matrix of the S3-10 coprolite. The botanical identification of the species was based on the stereomicroscope (source: D. Ngan-Tillard).

Figure 13.2 Small portion of white water-lily seeds (c. 2.2 x 1.5 mm in size), representing a handful of seeds usually obtain from one seed capsule (source: BIAX).

(see≈Fig. 13.1). In both coprolites, S3-10 and S3-11, an unusually large amount of *Nymphaea* pollen and fragments of *Nymphaea* alba seed testa are present as well. Also, the starch granules preserved in both coprolites, S3-10 and S3-11, are most likely from *Nymphaea* sp. seeds. The remains of water-lily seeds are also embedded in yet another (likely human) coprolite, S3-28, where they were accompanied by fish bones, apple seeds, and emmer chaff remains, all indicating the complexity of the Swifterbant diet. Rich in oil, starch and protein white water-lily seeds were likely used as food. Many small seeds would have been obtained just from one seed capsule (see Fig. 13.2). Whether however they were processed/cooked or what kind of food was produced from them cannot be concluded from the remains preserved.

Van Zeist and Palfenier-Vegter noticed that white water-lily (*Nymphaea alba*) seeds were remarkably well represented in macroremains assemblages from S3 and that most of the seeds were seriously damaged.[320] The *Nymphaea alba*

[320] Van Zeist & Palfenier-Vegter 1981.

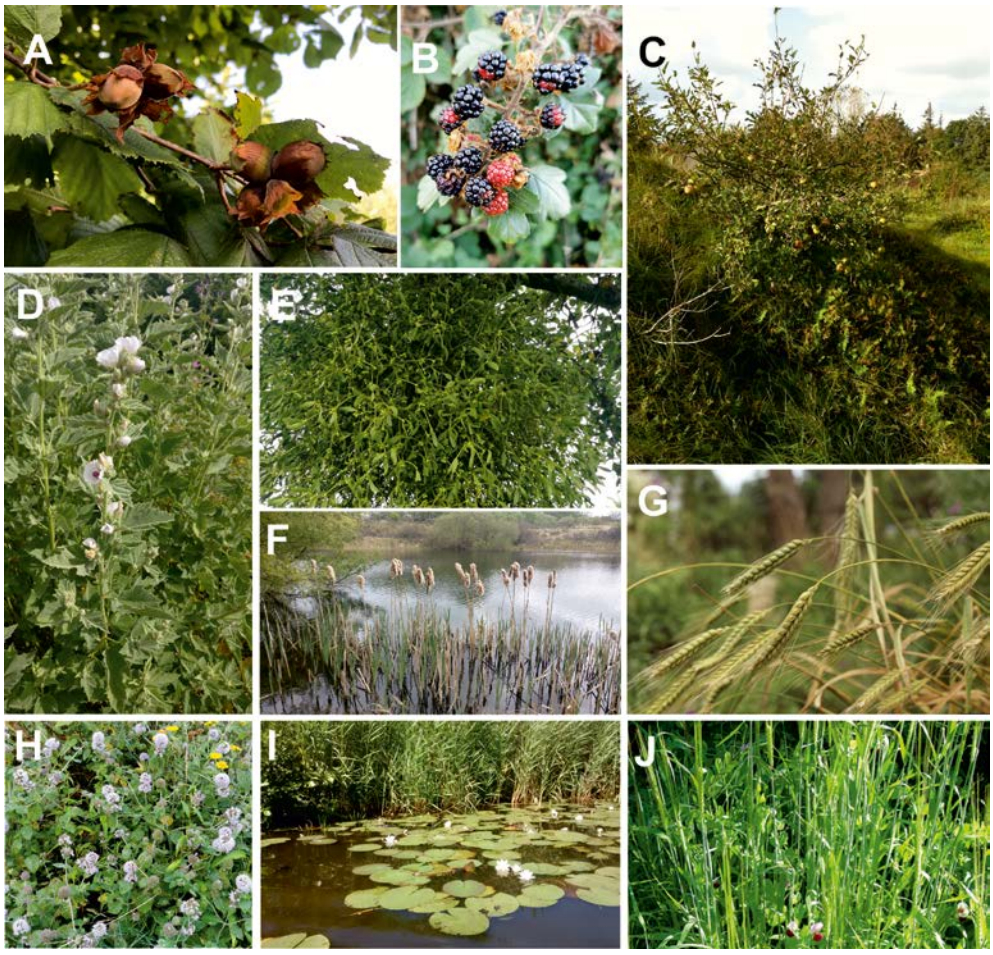

Figure 13.3 Examples of food plants of which remains were present in the Swifterbant coprolites. a: hazel, b: bramble, c: apple tree and polypody ferns in the undergrowth, d: marsh mallow, e: mistletoe, f: bulrush, g: emmer wheat, h: water mint, i: white water-lily with reed vegetation in the background, j: naked barley field (source: BIAX).

seeds were not present in or near (domestic) activity areas but were only found outside these areas. This might suggest some method of processing water-lily seed capsules in the area or areas dedicated to this work.

Palynological analysis showed that the pollen of food plants that would have been gathered was present in the coprolites. In addition to pollen, many microscopic fragments of (charred) epidermal tissue of leaves and, possibly, fruits were present. The presence of *Sorbus*-type pollen (including apple (*Malus*), hawthorn (*Crataegus*), and mountain-ash (*Sorbus aucuparia*)) and bramble (cf. *Rubus*) shows that trees and shrubs with edible fruits and berries were most likely eaten since pollen also sticks to the berries and fruits.[321] Probably the food plants were growing near the site. Some of the epidermal tissue found resembles that of apple (*Malus*) and bramble (*Rubus*). In the micro-CT scan of coprolite S3-10, an impression of an entire seed is visible and in the micro-CT scan and SEM image of coprolite S3-28, fragments of seeds of *Malus* were discovered, which confirms the consumption of crab apple. Both species are well known plant foods gathered in the Mesolithic and Neolithic.

In almost all of the coprolites, pollen of the food plant hazel (*Corylus*) is present. There shouldn't be any doubts that hazelnuts were gathered for food. At both the S3 and S4 sites, numerous finds of charred hazelnut shells were reported, which indicates that the nuts were processed.[322]

In the coprolites, pollen is also present of species of which no seeds were found during the earlier excavations. Of course, this may mean that these species were just not present in the

[321] Personal communication Linda Scott Cummings (1-10-2021) paper in prep. The author also observed strawberry pollen on fruit epidermis tissue when preparing collection material.

[322] Van Zeist & Palfenier-Vegter 1981; Schepers & Bottema-Mac Gillavry 2020; Schepers 2014.

archaeological samples - but were present in the local natural environment. For example, vetchling (*Lathyrus*) may have grown nearby the site or in the backswamps. But, for some taxa, the natural habitat differs from the reconstructed freshwater environment of the Swifterbant settlement. Two taxa marsh mallow (*Althaea officinalis*) and thrift/ sea lavender *(Armeria/Limonium*) for which pollen is present grow in a brackish to the marine environment. This may imply that the creeks near the settlement were, occasionally, slightly brackish. These conditions may have occurred - temporarily - after a marine flood. Or, this may imply that parts of these plants were - incidentally - gathered for consumption or consumed at other locations than the settlement site, in this case in a coastal environment. While people were traveling or collecting food, pollen of another vegetation type than at the settlement may have been inhaled. This may apply to marsh mallow and thrift/sea lavender which both have edible plant parts. The leaves, seeds, and tubers of marsh mallow are edible. An infusion of the flowers may be drunk as herbal tea. The leaves of *sea lavender* are also edible.

Honeysuckle *(Lonicera periclymenum*) pollen may point to the practice of sucking nectar from the tubular flowers. Perhaps, the presence of some pollen types e.g. heather (*Calluna vulgaris*) may point to the use of honey. Possibly, also the fruits of Ericaceae (e.g. blueberry) were gathered for food.

13.8.4 Roots and tubers

In many coprolites, vascular tissue (often charred), sponge parenchyma (probably of a leaf or stem tissues), and periderm (probably of roots and tubers) were found. These remains were difficult to assign to a single taxon. The presence of pollen of bulrush (*Typha latifolia*), water-lily (*Nymphaea*), and polypody (*Polypodium*) shows that plants with edible roots and tubers were growing in the nearby surroundings. The young leaves and the tubers of dropwort (*Filipendula* cf. *vulgaris*) may also have been collected. The tubers were likely consumed. Furthermore, many of these plants are used in herbal medicine. This will be discussed further in the health section below. The charred epidermal tissue of likely leek, onion or garlic (*Allium*) bulb found in one of the coprolites suggests that some species of wild onion or garlic would have been gathered for its bulbs and perhaps for its greens.

13.9 The animal component of the Early Swifterbant Culture diet

What we have learned from the micro-CT scans is that all 16 coprolites contained fish remains (Table 13.3). In only two cases were the fish bones accompanied by mammal bones and, in one case, duck bones. Interestingly, fish bone remains included vertebrae, fish scales, and head bones (including teeth). In all cases, the remains came from very small individuals (mainly pike but also cyprinid fish) of no more than 10 cm long. This, taken all together, would suggest that the whole fish was eaten. It was probably cooked in the vessels, which would have softened the bones. We have good evidence for this method of cooking fish from charred food residues, often filled with fish scales, encrusted on Swifterbant pottery.[323]

The bone analysis and CT-scans of the Hardinxveld coprolites (19520 and 19952) showed fish remains of mainly perch and of mammals. Duck bones could also be identified in Hardinxveld (19952). This indicates that perch and other fish, as well as ducks and mammals, were part of the diet at the Late Mesolithic-Early Neolithic Hardinxveld-Giessendam De Bruin. Hairs (fine wool) may point to the processing/ consumption of sheep meat or the use of sheep wool clothing or fabric. In addition to the bone data, the presence of helminths eggs of (possible) Fascioliidae family (in Hardinxveld 19952) points to the consumption of the meat of a herbivorous mammal (or possibly of the herbage). The lipid analysis showed that the coprolite itself was produced by a pig.

Also at Swifterbant, the main components of all of the studied coprolites were fish bones. This would suggest that fish was frequently eaten, perhaps on daily basis. Pike (*Esox lucius*), perch (*Perca fluviatilis*), and cyprinids (sometimes combined) were part of the diet. In coprolite S3-20, mammal bones were also found. The finds of hairs of sheep (fine wool in S3-13 and S3-15) and likely red deer (S3-11) may point to the processing/consumption of the meat of these animals or the processing of wool or fur. In

[323] Raemaekers, Kubiak-Martens & Oudemans 2013.

coprolite S3-10, a small fragment of a feather (barbule) from either a perching bird or a wader shows that these birds also formed a part of the diet or that feathers were used for other purposes like bedding or ornamentation. In addition to the bone data, the presence of parasite eggs of Diphyllobotriidae (fish tapeworms), Opisthorchiidae (liver flukes), *Dioctophyma* (kidney worm), and, possibly, also of *Capillaria* (hairworm) point to the consumption of freshwater fish and frogs. The consumption of entire small fish may have promoted infections with fish tapeworms. The diversity of animals processed either for their meat, fur, or wool is well-documented for the Swifterbant settlement. At both the S3 and S4 sites, bones from the domestic pig (and/or wild boar), cattle, sheep and/or goat, aurochs, beaver, otter, red deer, and other wild animals were documented.[324] The presence of dogs is also confirmed by their bone remains in archaeozoological assemblages from both the S3 and S4 sites.

In all the coprolites from S3 and S4 that were studied for intestinal parasites (S3-10, S3-11, S3-13, S3-28, S4-1, S4-4; except S3-4), *Trichuris trichiura/suis* eggs were present, implying human (or pig) component in all of these coprolites. *Trichuris* is a good indicator for faeces in the soil.[325] It is associated with the consumption of cultivated plants and with animal husbandry.[326] As for the Swifterbant Culture, the frequent presence of *Trichuris* may be seen as an indication for long-termpresence of animals and humans at one location. The composition of the intestinal parasites found in the Hardinxveld coprolite (19952) differed from the Swifterbant coprolites. At Hardinxveld, only large trematode eggs were present.

13.10 Drinking Water

In all of the coprolites, freshwater microfossils (green algae and diatoms) and marine microfossils (foraminifera and diatoms) are found. This may suggest that the drinking water was slightly brackish or that microfossils that

[324] Zeiler 1997; Kranenburg & Prummel 2020.
[325] Le Bailly & Bouchet 2005.
[326] Ledger *et al.* 2019; Reinhard *et al.* 2013.

Table 13.3 Overview of animal remains found in the Swifterbant coprolites.

Site	Find	Labcode	CT-scan	Bones	Pollen/IP	Helminths
Hardinx.	19520	.	fish	fish, perch; mammal	n.d.	n.d.
Hardinx.	19952	BX9300	fish	fish, perch; duck; mammal	sheep	herbivorous mammal (or herbage)
S3-2	54516	BX9099	fish, mammals	fish, pike, cyprinid	.	n.d.
S3-4	54655	BX9295	fish	.	.	possibly freshwater fish (or meat)
S3-5	51179	BX9296	fish	fish, pike	.	n.d.
S3-8		.	fish, perch	fish, perch	n.d.	n.d.
S3-10	54845	BX9100	fish	fish, cyprinid	perching birds/ waders	freshwater fish
S3-11	54827	BX9101	fish	n.d	likely red deer	freshwater fish
S3-13	53814	BX9297	fish	n.d	sheep	.
S3-15	43716	BX9102	fish	fish, pike	sheep	n.d.
S3-18	54752	BX9103	fish, perch	fish, perch	.	n.d.
S3-20	57443	BX9104	fish, pike, cyprinid, mammals	fish, pike, cyprinid; mammals	.	n.d.
S3-26	?	.	fish, pike, perch	fish, perch	n.d.	n.d.
S3-28	54488	BX9298	fish, pike, perch	fish, pike	.	freshwater fish
S4-1	1420	BX9299	fish	fish, pike	.	freshwater fish, frogs
S4-4	629	BX9105	fish	.	.	freshwater fish, frogs

emerged from the reworked marine clay bedding of the creek were present in the drinking water. During the S4 excavation, the diatoms were studied, showing that marine species are broken and those from the fresh-water environment are not. This implies that the marine diatoms probably represent reworked microfossils. This would also apply to some of the pollen types present in the coprolites. Presumably, these would mostly represent aquatic plants and shore vegetation. Pollen of pine (*Pinus*) and alder (*Alnus*) and spores of buckler/male fern (*Dryopteris*) and peat moss (*Sphagnum*) are also easily transported by water. These pollen types may represent local vegetation or were present in reworked peat deposits or sediments.

13.11 Natural environment

The pollen and microfossil composition of both the Hardinxveld-Giessendam De Bruin and Swifterbant coprolites confirms that the Swifterbant people lived in a freshwater environment that was under marine influence. Near the settlements, open spaces were present in the wetlands and forests. Although a large part of the pollen present in the coprolites may be derived from food plants and does not reflect the actual vegetation, the pollen composition provides information about the surrounding vegetation in a general way (see section 10.4.3).

13.12 Seasonality

Based on the pollen composition of the coprolites no seasonality, the presence of pollen produced in a certain season could be demonstrated. On the contrary, pollen of species that bloom in different seasons was found in the same coprolite. This can be explained by the presence of pollen on various substrates and objects in a living area. When pollen is around it can be breathed in. Fruits may well have a bit of pollen on their parts which is consumed in another season than when the plant was flowering. Also if food plants were stored and consumed later, pollen of different seasons may end up in one coprolite. Leaves of knotgrass but also other green vegetables, for example, leaves of wild onion/garlic were likely gathered and consumed in spring through early summer. The best time of the year to collect seed capsules of the white water-lily would have been in late summer. Late summer would also be the right time of the year to collect crab apples, which would be followed by hazelnuts in early autumn.

The presence of bones of entire, small-sized fish (mostly pike and cyprinids) may be an indication of the season(s) the fish were caught. For example, the spawning season of pike is from February to May. Pike eggs hatch after 10-15 days. The young fish can already grow up to 10-30 cm in their first season. Cyprinids' spawning seasons are in spring and summer. These all would mean that the small-sized fish would have been available (in large numbers) from early spring through summer. Probably the small fish were consumed in their entirety in a soup or stew. Perhaps, the small fish were preserved in some way (dried or smoked?) for later use, but no indications were present to support this hypothesis.

13.13 Health and hygiene

The presence of eggs of different flatworm taxa at both Hardinxveld-Giessendam De Bruin and Swifterbant implies that raw or undercooked food of animal or plant origin was consumed. This led to worm infections of liver flukes at Hardinxveld-Giessendam De Bruin and flatworm and roundworm infections of fish tapeworms, liver flukes, hairworms, and kidney worms at Swifterbant. At Swifterbant, the presence of geohelminth whipworm (*Trichuris*) indicates that faecal matter was present in the soil. Overall, the hygienic conditions were poor at the Swifterbant settlement. Without treatment, these multiple parasitic worm infections probably led to serious health issues. Symptoms would have included abdominal pain, diarrhoea, obstruction of the intestines, liver and kidney damage. In the most severe cases, for example, infections of kidney worms could have led, ultimately, to death. In the coprolites, pollen and spores of several plants that can be used as herbal medicine to treat these symptoms were found. For example, infusions of the roots from buckler/male fern (*Dryopteris*), polypody (*Polypodium*), or dropwort

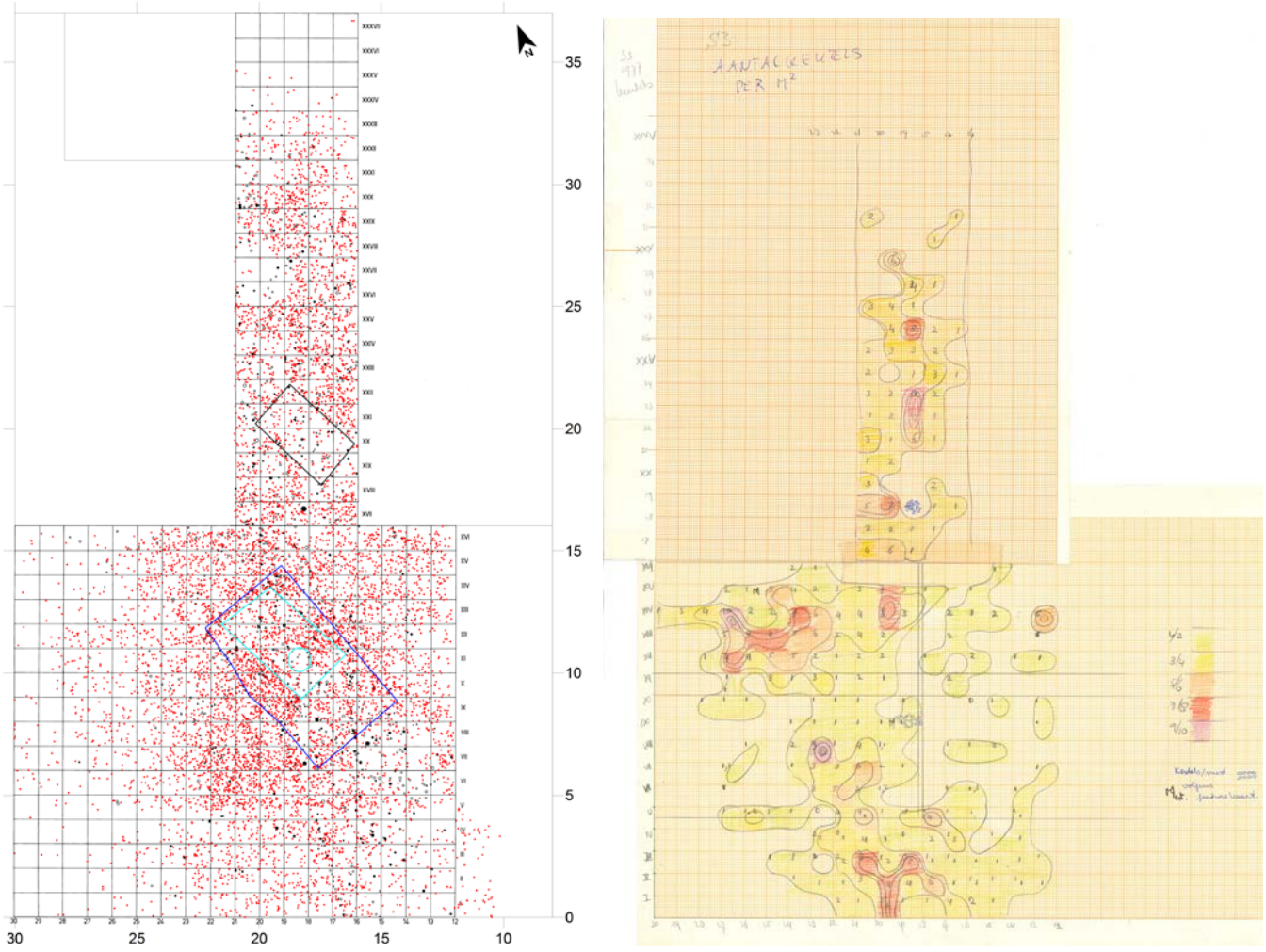

Figure 13.4 Swifterbant-S3 site, showing a. the outline of the houseplan postulated in the center of the site (c. 8 x 4.5-meter rectangular structure), and a possible small house in the north (after Devriendt 2014), and b. spatial distribution of coprolite clusters (as documented in the field, source: archaeological depot Province of Flevoland, Lelystad).

(*Filipendula vulgaris*) have anthelminthic properties (antiparasitic). Leaves from knotgrass (*Polygonum aviculare*), ivy (*Hedera helix*), and meadowsweet (*Filipendula ulmaria*) have medical properties that help against diarrhoea, mistletoe (*Viscum album*) leaves have diuretic properties (causing the increased passage of urine), and treatments with plant parts of marsh mallow (*Althaea officinalis*) help against abdominal pain (or dysentery).[327] It is unknown whether the Swifterbant people were aware of these remedies. Perhaps self-medication was practised. Self-medication is the consumption of plants not for their nutritional value but for their medicinal properties. The issue of self-medication has been studied in higher primates, revealing extensive evidence demonstrating the complex use of medicinal plants.[328] Some primates roll balls of leaves of specific plants and swallow these balls whole. Therefore, the faeces of primates sometimes contain unchewed leaves which points to the possibility that these leaves were not eaten for nutrition. Parasitic worms were found together with the leaves in the stool.[329] One may wonder if the preservation of knotgrass leaves as rolled or scroll-like fragments embedded in coprolite matrices in some of the studied coprolites indicates food or medicine. The consumption of plants without nutritional value is also witnessed in other animals. Common plant secondary compounds such as terpenes and anthraquinones may have a medicinal effect (diuretic and purgative, respectively) on animals and humans.[330] The study of the mummy of the iceman Ötzi, found in the Alps, suggested that 5300 years ago this

327 Launert 1984; Chiej, 1984; Van Os 1974; Starý & Jirasék 1990; Moerman 2009; Prendergast *et al.* 1998.
328 Cousins & Huffman 2002; Huffman 1997; Hardy *et al.* 2012.
329 Fowler, Koutsioni & Sommer 2007.
330 Huffman & Vitazkova 2011.

man was aware of the intestinal parasites (*Trichuris trichiura*) in his body and that he treated himself with measured doses of toxic resins of a bracket fungus.[331]

Although the ability to self-medicate among the Swifterbant populations must, of course, remain open to speculation, it is unimaginable to think that these groups did not have any knowledge of the medicinal plants within their environments. Ethnobotany studies have shown that indigenous peoples from the Americas use many herbal treatments.[332] Also, nowadays, in many traditional human societies around the world, people are still very much dependent on plants for both food and medicine. At Swifterbant, the presence of most of the plant taxa can also be explained as part of the regular diet. More research is needed on this subject to reach more clear conclusions.

One of the questions related to the hygienic conditions on the Swifterbant sites is where the acts of defecation have taken place? If we look at the map of the spatial distribution of coprolites as they were plotted during excavation at the Swifterbant-S3 site, several small clusters can be observed. These were formed by the frequency of coprolite occurrences per one square meter (see Fig. 13.14 b).[333] If we compare the distribution of these coprolite clusters with the location of the houseplan in the center of the site postulated for the S3 site[334], it appears that they do not overlap with the outline of the house (see Fig. 13.14 a). This would further suggest that the acts of defecation would have taken place outside the house, and more specifically, south and northwest of the house. If yet another small house should be located more to the north (Fig. 13.14 a), also there (Fig. 13.14 b), the clusters of coprolites are found outside the outline of the house.

13.14 NOaA 2.0 question 7: How did the way of life change from the Late Mesolithic until the Neolithic?

From the mid-fifth millennium cal BC onwards, various aspects of a Neolithic lifestyle become apparent in the archaeological record, including a more settled way of life, animal husbandry, the consumption of cereals, and the cultivation of cereals on a structural, but small-scale basis.[335] During the Late Mesolithic and Early Neolithic people settled down and kept domesticated animals on the sites. Flesh, wool, and other animal products could be used. The consumption of animal meat resulted in zoonoses (infections caused by the spread of parasites from animals to humans). People were infected with intestinal parasites caused by the ingestion of undercooked meat. Faeces built up in the soil nearby the houses would have caused the whipworm infections. Cereals became part of the diet during the Early Neolithic Swifterbant Culture. Cereals such as barley and emmer wheat were an addition to gathered plant foods. Due to the finds of tilled fields at S4, it seems likely that the cereals were grown on the river banks near the settlement. Even though the micromorphological evidence attests to local cultivation, the introduction of cereals to the Swifterbant sites probably happened through contact with other farming groups. Van Zeist and Palfenier-Vegter have made a comparison between the cereal assemblage from the Swifterbant-S3 site and those from the Rössen culture in the German Rhineland area, highlighting similarities that would imply contact.[336] Archaeobotanical finds from the recently excavated Swifterbant settlement in Tiel Medel-De Roeskamp, suggest contacts with either the Bischheim groups in the Rhineland or with the early Michelsberg farmers.[337] The contacts between the Neolithic groups, however, concerned not only the cereals but also the trading of goods, also well-documented for Tiel Medel-De Roeskamp, and suggests contacts with the Rössen (or Epi-Rössen) and/or the Bischheim groups in the Rhineland area.[338] One of the most evident methods of transportation during the Neolithic, particularly through the wetland territories, would have been by canoe. Perhaps the people of the Swifterbant area were in contact via trading of goods with people living upstream of the Vecht River system in the Münsterland area. In this way, they could also have been in contact with other Neolithic groups from the Bischheim and/or early Michelsberg cultures living in the German Rhineland.[339]

A bead made of a single carbonised stone of sloe (*Prunus spinosa*) found at the Swifterbant-S4 site, may also suggest contact with other Neolithic groups.[340] Interestingly, sloe was not known from the Swifterbant archaeobotanical

331 Capasso 1998.
332 Moerman 2009.
333 As the spatial coordinates of the coprolite finds are not available, we use the field drawing for the purpose of this study. The darker colour the more coprolites were found within 1m².
334 Roever 2004, Devriendt 2014.
335 Raemaekers *et al.* 2021.
336 Van Zeist & Palfenier-Vegter 1981.
337 Kubiak-Martens (in prep.).
338 Ten Anscher & Knippenberg 2022.
339 Kreuz *et al.* 2014, Ten Anscher & Knippenberg 2022.
340 Schepers & Bottema-Mac Gillavry 2020.

record. Furthermore, it represented a tradition of bead making that was unknown in the Netherlands. However, it seems to be a phenomenon in the Neolithic period of middle and eastern Europe.[341] One of the best analogies for the Swifterbant S4 sloe bead is the finds from the Neolithic lakeshore settlements, Hornstaad Hörnle (3917-3905 cal BC) and Arbon Bleiche 3 (3385-3370 cal BC), both located on the shores of the Bodensee/Lake Constance.[342] The specialised production of sloe stone beads has been ascribed to Hornstaad Hörnle.[343] Even though both sites are quite a distance from the Swifterbant area, and Arbon Bleiche 3 is somewhat younger, the Rhine River as well as the Rhine delta and the Vecht river system (see figures 1.1 and 2.2) would have offered a geographical connection between various Neolithic groups.

Even though there was no direct connection between the Rhine system and the Swifterbant area in the Neolithic time, still, there may have been connections. Traveling by canoe via waterways such as the Rhine River and the Vecht River (considering Rheinland hinterlands are the source area of the Vecht river system) or via coastal navigation (from the Rhein delta to the North Sea) may have been a very logical way to establish contacts between peoples, migration, and perhaps even have offered a route of entry for the Swifterbant cereal cultivation, and perhaps also for the sloe bead. Interestingly, there are more similarities between the Swifterbant sites and Arbon Bleiche 3. At both sites, mistletoe leaves were used as animal fodder and the coprolites of both locations have a very similar intestinal parasite composition which suggests a comparable lifestyle and diet. Fish tapeworm, fluke and kidney worm infections show that (undercooked) freshwater fish was consumed. The frequent presence of the faecal-borne parasite *Trichuris* shows that this geohelminth proliferated in such living conditions.

Animal domestication and the consumption of the meat of infected animals increased the presence of zoonotic parasites. Adopting new food habits therefore also led to transitions in parasitic infections in humans. Migration or trade contacts between Neolithic groups may have, indirectly, promoted new parasitic infections. Since hardly any Neolithic coprolites (let alone Mesolithic ones) from Dutch prehistoric sites have been studied for intestinal parasites it is hard to conclude. It certainly raises new research questions.

13.15 NOaA 2.0 question 8: Which landscape zones were used in the Late Mesolithic and Early Neolithic for habitation, hunting, arable farming and livestock?

The Late Mesolithic-Early Neolithic Hardinxveld-Giessendam De Bruin site was located on a river bank, in a freshwater environment. Livestock was bred at the site. People were fishing in the nearby waters. The Early Neolithic sites Swifterbant -S3 and -S4 were situated in a freshwater environment. The river banks were used for habitation, arable farming and livestock. Hunting and fowling took place in the backswamp and possibly also on the coastal plains. Food plants were gathered from the nearby vegetation as well as from the coastal areas. Fishing activities mainly took place in a fresh water environment but possibly also in the coastal waters.

13.16 NOaA 2.0 question 22: What role did the exploitation of natural food resources play after the introduction of agriculture?

This research showed that cereals formed a small part of the finds in the Swifterbant coprolite. This however might be partially due to the preservation of cereal remains in coprolite matrices in general. The fact that the cereals were only presented in small numbers of chaff remains, would be expected if they were de-hushed as part of the food preparation process, which -at Swifterbant sites - would be the case of emmer wheat. Consequently, a small portion of emmer light chaff (or husks) would enter the cooking pots together with the grain. Naked barley would enter the cooking pots as true clean grain, giving even less chance to be represented by its chaff in the coprolites. Other remains than emmer or barley husks, for example, grain starchy endosperm, would likely not preserve in coprolites. Still, few fragments of

[341] Schlichtherle 1988, after Schepers & Bottema-Mac Gillavry 2020.
[342] Schepers & Bottema-Mac Gillavry 2020.
[343] Maier 2001; Hosch 2004.

grain pericarp tissue from both wheat and barley were preserved on pollen slides, giving the best indication for consumption of both cereals. Adding up all the evidence, it can be concluded that cereals formed a regular and consistent contribution to the Swifterbant diet.

Natural food resources would have played a significant role. Food plants would have been gathered, for example, for starchy seeds (white water-lily), starchy roots and tubers (dropwort, marsh mallow, polypody), bulbs (leek, onion or garlic), greens (knotgrass and possibly leek), fruits (crab apples, berries) and hazelnuts. Furthermore, freshwater fish (pike, perch and cyprinids) formed a large part of the diet. Possibly game (red deer) and birds (waders) were eaten as well. Only a small portion of the bone material in the Swifterbant coprolites pointed to the consumption of mammals. See section 13.8 for a more detailed description.

13.17 Concluding remarks

Although this project aimed to reconstruct the Neolithic human diet based on human coprolites from the Swifterbant sites - and we integrated multiple research methods to achieve this - we may have to see our contribution as a reconstruction of the Swifterbant community diet. It seems that clarifying the diet on the level of individual species (humans, specifically) might be quite challenging, if not impossible. Particularly at archaeological sites where people were living together with their dogs (and pigs, nearby), the differentiation between human and dog (and pig) coprolites is complicated. It is likely that they all had a similar diet and that the people shared their space and the remains of food preparations with their animals.

Still, we feel that we have learned much about the dietary components of the Swifterbant culinary tradition as identified through multiple proxies. Furthermore, we have highlighted dietary trends in food preparations and indicated a highly variable diet. Based on the intestinal parasite study, it seems that the individual and community health at Swifterbant settlements would have been seriously compromised.

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Appendices

I Morphological characteristics of pre-selected coprolites (Chapter 4)

Site	Sample number	Coprolite code	Specimen description	Selection based on coprolite morphology	Possible source producer, based on visual observation	Preservation
Hardinxveld-Giessendam De Bruin (excavation 1996). Archaeological depot Province of Zuid-Holland, Alphen aan den Rijn						
	7552	7552	1x cylindrical coprolite with one end shaped by anus, fine matrix (drilling hole left after sub-sampling for pollen analysis in 1998), no bone remains embedded but some hair	yes	carnivores/ omnivores (?animal)	mineralized
	8877	8877	only fragments preserved, incl. bone frgs, likely from one coprolite	no	carnivores/ omnivores (?animal)	mineralized
	18819	18819	fragmented to pulverized, incl. bone frgs, likely from one coprolite	no	carnivores/ omnivores (animal)	mineralized
	19520	19520	1x ellipsoidal coprolite with cracks on the surface, fine matrix but also small bone frgs embedded in the matrix	yes	carnivores/ omnivores (?animal)	mineralized
	19952	19952	multiple fragments, fluffy pieces with ragged edges, many bone frgs embedded in the matrix, incl. fisch scales	yes	carnivores/ omnivores (?animal)	mineralized
Swifterbant S3 (excavation 1976-1977). Archaeological depot of Province of Flevoland, Lelystad (Box nr 413, L=558)						
	44993	S3-1	1big coprolite (with a small fragment broken off), rough surface, big bone frags. embedded in the matrix (incl. fish vertebra bone frgs.). Specimen described as 'mooie keutel' on the find original bag	no	carnivores/ omnivores (?animal)	mineralized
	54516	S3-2	1x big coprolite (in two pieces, reconstructed for photography), sausage-like shape, tapered at one end, rough surface, small & large bone frgs (incl. fish vertebrae) & plant tissue embedded in the matrix; few small burnt bones	yes	omnivores (?dog/human)	mineralized/ desiccated
	54384	S3-3	1 'cake-like' coprolite with bone frgs. & plant tissue emebedded in the matrix	no	omnivores (?pig)	mineralized
	54655	S3-4	2x big coprolites, sausage-like shape but lumpy with characteristic cracks on the surface, one tapered at one end, small bone frgs emedded in the matix	yes	possibly human	mineralized
	51179	S3-5	1x coprolite, cylindrical, unsegmented . Rough surface. Small bone frgs emedded in the matrix, fine matrix	yes	most likely omnivores (?dog/human)	mineralized
	43724	S3-6	5 big coprolite frgs. (3x most likely the same origin), irregular surface, fine matrix with plant tissue visible, no bone	no	herbivore (?cattle)	mineralized/ desiccated
	54237	S3-7	1 coprolite (now in two pieces), big bone frgs embedded in the matrix	no	carnivores/ omnivores (?animal)	mineralized
	53985	S3-8	1x 'cake-like' coprolite, roundish-ellipsoidal, slightly flattened (now in two pieces), fine bone frgs & fish scales emedded in the matrix, also plant tissue; few charred bones	yes	omnivores (animal, possibly pig?)	mineralized/ desiccated
	57866	S3-9	1x big/huge cake with much plant tissue emedded in the matrix (herbaceous stem frgs)	no	herbivore (?cattle)	mineralized/ desiccated
	54845	S3-10	3x coprolites, huge (one act of defecation). Cylindrical, unsegmented. One of the coprolites tapered at one end. With seeds of Nymphaea alba emebedded in the matrix (seed testa, seed outlines preserved), also small & bigger bone frgs	yes	possibly human	mineralized
	54827	S3-11	1x coprolite (resembles sample S3-10 nr. 54845), many seed testa frgs of Nymphaea alba, also bone frgs (fish vertebra bone), small & large bones.	yes	possibly human	mineralized
	53842	S3-12	2 coprolite fragments (one act of defecation), sausage-like shape, tapered atvone end, rough surface, with small fish bones (a lot!) and plant tissue embedded in the matrix	yes	omnivores (animal/human)	mineralized
	53814	S3-13	1x coprolite (now in two pieces), sausage-like shape, smooth surface, tapered at one end, fine matrix, small and large bone frgs embedded in the matrix	yes	omnivores (?dog)	mineralized
	53617	S3-14	1x 'drop-shaped' coprolite, fine matrix, described as 'mooie museum exemplar'	no	?animal?	mineralized

Site	Sample number	Coprolite code	Specimen description	Selection based on coprolite morphology	Possible source producer, based on visual observation	Preservation
	43716	S3-15	5 large pieces (most likely from one act of defecation). Separated lumps with a segmented surface (possibly originally sausage-shaped but lumpy). Described as 'mensen keutel' on the original bag. Small bone frgs & fish scales embedded in the matrices. Some large bones.	yes	possibly human	mineralized
	55061	S3-16	2 pieces (most likely from one coprolite), lump-like form, somewhat rounded, small bone frgs and possible plant tissue emedded in the matrix	no	omnivores (?pig)	partially mineralized/ desiccated
	45575	S3-17	lump-like coprolite (in two pieces), much plant tissue embedded in the matrix	no	herbivore (?cattle)	partially mineralized/ desiccated
	54752	S3-18	1x coprolite with wrinkled surface and cracks, sausage-like shape, fine matrix, small bone frgs embedded in the matrix	yes	possibly human	partially mineralized/ desiccated
	57328	S3-19	1x coprolite, cylindrical, small bones embedded in fine matrix	yes	most likely omnivores (?dog/human)	partially mineralized/ desiccated
	57443	S3-20	2 big fragments from one coprolite, sausage-like shape, surface with cracks, fine matrix, bone (incl. fish vertebrae) & plant tissue embedded in the matrix; few charred bones embedded in the matrix	yes	omnivores (?dog/human)	partially mineralized
	54663	S3-21	1 coprolite fragment, rounded to irregular shape, small bone frgs embedded in the matrix, also plant tissue	no	omnivores (?pig)	mineralized
	43955	S3-22	2 coprolite fragments (one origin), irregular shape, fish bone (vertebra) embedded, also plant tissue embedded	no	omnivores	mineralized
	54240	S3-23	1x coprolite, cylindrical, rather smooth surface, fine matrix, small bone frgs embedded	yes	omnivores (?human)	mineralized
	57363	S3-24	1x cylindrical coprolite with one end shaped by anus, some cracks on the surface, fine bone frgs embedded	no	carnivores/ omnivores (?animal)	mineralized
	54202	S3-25	1x more or less cylindrical coprolite with one end shaped by anus with some cracks on the surface, fine matrix, small bone frgs embedded in the matrix	no	carnivores/ omnivores (?animal)	mineralized
	53954	S3-26	1x coprolite, sausage-like, rather smooth surface with some cracks, tapered at one end, small & large bone frgs embedded in fine matrix	yes	most likely omnivores (?dog/human)	mineralized
	54052	S3-27	1xcoprolite fragment, small bone frgs & plant tissue embedded	yes	omnivores (?dog/human)	mineralized
	54488	S3-28	3x coprolites, separated hard lumps (one act of defecation), characteristic cracks on the surface, fish scales embedded, few small bone frgs, possible also plant tissue. Fine matrix.	yes	possibly human	mineralized
	45691	S3-29	1 coprolite frg (cut off on one side?), cylindrical, irregular shape, some cracks on the surface, small & large bone frgs embedded, fish vertebrae, also plant tissue	yes	omnivores (?dog/human)	mineralized
	54809	S3-30	3 coprolites (one example on the photo). Some cracks on the surface, bone frgs embedded,	no	carnivores/ omnivores	mineralized
Swifterbant S4 (excavation 1974). Archaeological depot of Province of Depot Flevoland, Lelystad (Box nr. 269)						
	1420	S4-1	3x coprolites (one act of defecation), sausage-like shape, rough surface, very fragile/brittle, many small bone frgs emedded (incl. fish vertebra bone)	yes	omnivores (?dog/human)	mineralized
	1380	S4-2	1 big coprolite with many bone frgs embedded in the matrix, smooth surface	no	omnivores	mineralized
	1366	S4-3	1 coprolite fragment, cylidrical? with fine matrix, some small bone frgs emedded in the matrix, rather smooth surface	yes	omnivores (?dog)	mineralized
	629	S4-4	1 coprolite frgs with fine matrix, cylindrical, flattened, small bone frgs embedded in the matrix	yes	omnivores (?dog/human)	partially mineralized
	1384	S4-5	1 coprolite frgs with fish bone (incl. vertebrae bone) embedded in the matrix	no	omnivores	partially mineralized
	1184	1	2 coprolite fragments (one act of defecation), rough surface, large bones embedded in the matrix	yes	carnivores/ omnivores	mineralized
	1177	2	1x drop-shaped coprolite, tapered on one end, many fish bones embedded in the matrix	yes	carnivores/ omnivores (?animal)	mineralized

II Catalogue of selected coprolites (Chapter 4)

The plate number is given as a Roman numeral. The coprolites from Hardinxveld-Giessendam De Bruin and Emmeloord are presented in the catalogue with their sample numbers given during the archaeological excavation. For all the coprolites from the Swifterbant -S3 and -S4, the plate number is followed by the coprolite code number and the sample number. For example Plate I. S3-2, sample number 54516 indicates that this object is depicted on plate I, the coprolite is from the Swifterbant -S3 site and its given code in this project is S3-2; the original sample number given during the archaeological excavation is 54516. Each coprolite is morphologically described in the Catalogue.

Plate I. Hardinxveld-Giessendam De Bruin 7552

Morphological description: one cylindrical coprolite with one end shaped by anus, fine matrix, no bone remains embedded but some hair (drilled hole left after subsampling for pollen analysis in 1998).

Plate II. Hardinxveld-Giessendam De Bruin 19520

Morphological description: one ellipsoidal coprolite with cracks on the surface with small bone fragments embedded in a fine matrix.

Plate III. Hardinxveld-Giessendam De Bruin 19952

Morphological description: multiple fragments, fluffy pieces with ragged edges, many bone fragments embedded in the matrix, including fish scales.

Plate IV. S3-2, sample number 54516

Morphological description: a. One large coprolite (in two pieces, reconstructed for photography), sausage-like shape, tapered at one end, rough surface, small and large bone fragments (including fish vertebrae) and plant tissue embedded in the matrix; also a few small burnt bones. b. Detail showing fish vertebra bone embedded in coprolite matrix.

Plate V. S3-4, sample number 54655

Morphological description: two coprolites, sausage-like shape but lumpy with characteristic cracks on the surface, one tapered at one end with small bone fragments embedded in the coprolite matrix.

Plate VI. S3-5, sample number 51179

Morphological description: one coprolite, cylindrical, unsegmented. Rough surface. Small bone fragments embedded in the fine matrix.

Morphological description: one ‘cake-like’ coprolite, roundish-ellipsoidal, slightly flattened (now in two pieces). Fine bone fragments, fish scales, and plant tissue embedded in the matrix as well as a few charred bones.

Plate VIII. S3-10, sample number 54845

Morphological description: three coprolites (one act of defecation), cylindrical, unsegmented. One of the coprolites tapered at one end. Seeds of white water-lily (*Nymphaea alba*) (mainly seed testa remains) embedded in the matrix, also small and large bone fragments.

Morphological description: one coprolite (resembles finds from S3-10, sample number 54845), many seed fragments (testa remains) of white water-lily (*Nymphaea alba*) embedded in coprolite matrix, also small and large bone fragments (including fish vertebra bones).

Plate X. S3-12, sample number 53842

Morphological description: two coprolite fragments (one act of defecation), a: Sausage-like shape, tapered at one end, rough surface, with many small fish bones and plant tissue embedded in the matrix, b: Detail is good! sowing fish bone and plant fragment distribution.

Plate XI. S3-13, sample number 53814

Morphological description: one coprolite (now in two pieces), sausage-like shape, smooth surface, tapered at one end, fine matrix, small and large bone fragments embedded in the matrix.

Plate XII. S3-15, sample number 53814

Morphological description: a. Overview of five large coprolites (most likely from one act of defecation). Separated lumps with a segmented surface (possibly originally sausage-shaped but lumpy). Described as ‘mensen keutel’ [human pellets] on the original bag. Small bone fragments and fish scales embedded in the matrices as well as some large bones. b. Detail showing fish vertebra bones embedded in coprolite matrix.

Plate XIII. S3-18, sample number 54752

Morphological description: one coprolite with wrinkled surface and cracks, sausage-like shape, fine matrix, small bone fragments embedded in the matrix.

Plate XIV. S3-19, sample number 57328

Morphological description: one coprolite, cylindrical, small bones embedded in fine matrix.

Morphological description: two coprolites (most likely from one act of defecation), sausage-like shape, surface with cracks, fine matrix, bone (including fish vertebrae) and plant tissue embedded in the matrix. A few charred bones embedded in the matrix.

Plate XVI. S3-23, sample number 54240

Morphological description: one coprolite, cylindrical, rather smooth surface, fine matrix, small bone fragments embedded in coprolite matrix.

Plate XVII. S3-26, sample number 53954

Morphological description: one coprolite, sausage-like, rather smooth surface with some cracks, tapered at one end, small and large bone fragments embedded in fine matrix.

Plate XVIII. S3-27, sample number 54052

Morphological description: one coprolite fragment, small bone fragments and plant tissue embedded in the matrix.

Plate XIX. S3-28, sample number 54488

Morphological description: three coprolites, separated hard lumps from likely one act of defecation, characteristic cracks on the surface. Fish scales and a few small bone fragments embedded in coprolite matrices. Possible plant tissue. Fine matrix.

Plate XX. S3-29, sample number 45691

Morphological description: one coprolite fragment, cylindrical, irregular shape, some cracks on the surface, small and large bone fragments embedded in coprolite matrix, fish vertebrae, also plant tissue.

Plate XXI. S4-1, sample number 1420

Morphological description: three coprolites (one act of defecation), sausage-like shape, rough surface, very fragile/brittle, many small bone fragments embedded in coprolite matrix, including fish vertebra bones.

Plate XXII. S4-3, sample number 1366

Morphological description: one coprolite fragment, cylindrical with fine matrix, some small bone fragments embedded in the matrix, rather smooth surface.

Plate XXIII. S4-4, sample number 629

Morphological description: one coprolite fragment with fine matrix, cylindrical, flattened, small bone fragments embedded in the matrix.

Plate XXIV. Emmeloord-J78-91, sample number 1177

Morphological description: one teardrop-shaped coprolite, tapered on one end, many fish bones embedded in the matrix.

Plate XXV. Emmeloord-J78-91, sample number 1184

Morphological description: Two coprolite fragments (one act of defecation), rough surface, large fish bones embedded in the matrix (one of the two specimens photographed).

III Micro-CT scans 1: Scan parameters and link to videos (Chapter 6)

All scans of coprolites were made in mode 0 with 1440 rotation positions, 500 ms exposure per image, four images averaged and one skipped per position, except for S3-4 and S3-10 Top sample and S3-18 (five images averaged, one skipped). Coprolites were glued on top of a wooden stick and vertebras on top of a glass rod. The scans of the coprolites were recorded in 3 batches. The scans of S3-2, S3-10, S3-11, S3-15, S3-18, S3-20, and S4-4 were acquired in Nov-Dec 2019, the scans of coprolites S4-1, Hardinxveld 19520, S3-4, S3-13, S3-26, and S3-28 in January and February 2020, and the scans of Hardinxveld 19552, S3-5, and S3-8 in April 2020. The scans of the vertebras were made in July 2020, and the scan of the pike teeth, in September 2020. All scans of the coprolites were reconstructed at "half resolution", i.e., twice the voxel size of the scan, except the sub-scan S3-18 Top. The scans of the individual bones (vertebras and pike teeth) were reconstructed at "full resolution". Note that the voxel size of the reconstruction is indicated in the captions of the figures of the main text and of appendices IV and V. Table II.1 gives an overview of the scans and scan parameters. V and A are the voltage and amperage of the X-ray beam. FOD is the focus to object distance, FDD, the focus to detector distance and Ys is the elevation of the rotation platform. Table II.1 also indicates scans from which a video has been produced. The videos can be downloaded from the TU Delft SurfDrive via: https://surfdrive.surf.nl/files/index.php/s/3S2G79HrsvFuanY

Table III.1 Inventory of scans with scan parameters and scans with videos.

Coprolite	Code	Name of Sub-scan	V (keV)	A (µA)	Ys (mm)	FOD (mm)	FDD (mm)	Scan voxel size (µm)	Videos (yes=V)
Hardinxveld	7552								
Hardinxveld	19520		100	190	102	100	286	17.5	V
Hardinxveld	19952		100	210	118	50	313	8	V
S3-2	54516		100	200	102	120	300	20	V
		small A	90	100	76	22	200	5.5	V
S3-4	54655		90	230	103	100	286	17.5	V
		top	100	160		66	300	10	V
S3-5	51179		90	180	69.2	65	250	12.5	V
S3-8	53985		90	180		70	250	14	V
S3-10	54845		100	200	99	120	300	20	V
		top sample	90	100	38	46	211	10.9	V
S3-11	54827		100	110	59	63	250	12.5	V
S3-12	53842								
S3-15	43716		100	200	102	120	300	20	V
		detail A top	90	100	33	22	200	5.5	V
		detail B middle	90	100	48	22	200	5.5	V
S3-13	53814		90	180	108	60	250	12	V
		top	100	160		66	300	10	V
S3-18	54752		100	200	109	75	300	12.5	
		top A			54.5	45	250	9	V
		Pike teeth	90	140	82	15	200	3.75	
S3-19	57328								
S3-20	57443		100	190	101	120	300	20	V
		top A	90	100	34.5	20	200	5	
		Pike vertebra				200	86	4	
		Cyprinid vertebra			81.9	11	200	2.75	

Coprolite	Code	Name of Sub-scan	V (keV)	A (µA)	Ys (mm)	FOD (mm)	FDD (mm)	Scan voxel size (µm)	Videos (yes=V)
S3-23	54240								
S3-26	53954		80	210	106.5	64.4	230	14	V
S3-27	54052								
S3-28	54488		90	230	57.5	88	275	16	V
S3-29	45691								
S4-1	1420		90	180	99.5	70	250	14	V
S4-3	1366								
S4-4	629		100	190	109	75	300	12.5	V

IV Micro-CT scans 2: Inventory of coprolite shapes and microstructures (Chapter 6)

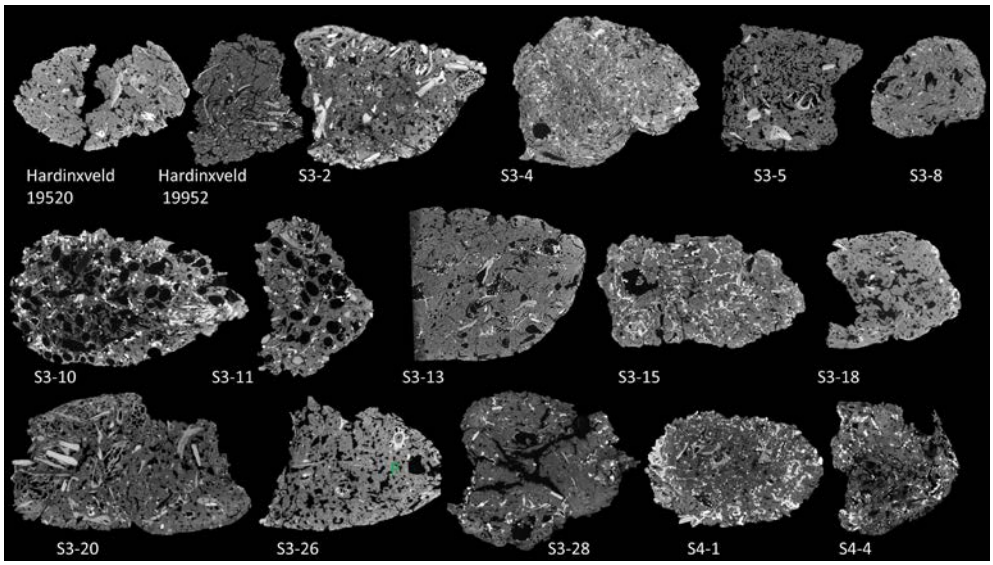


Figure IV.1 Overview of vertical micro-CT scan slices through the scanned coprolites.

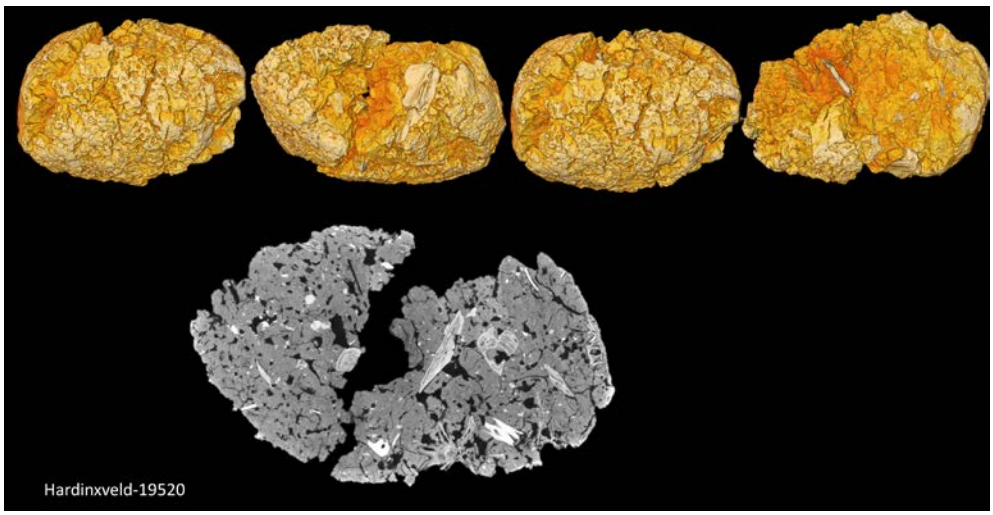


Figure IV.2 Coprolite Hardinxveld 19520. Volume rendering of coprolite volume and vertical micro-CT scan slice.

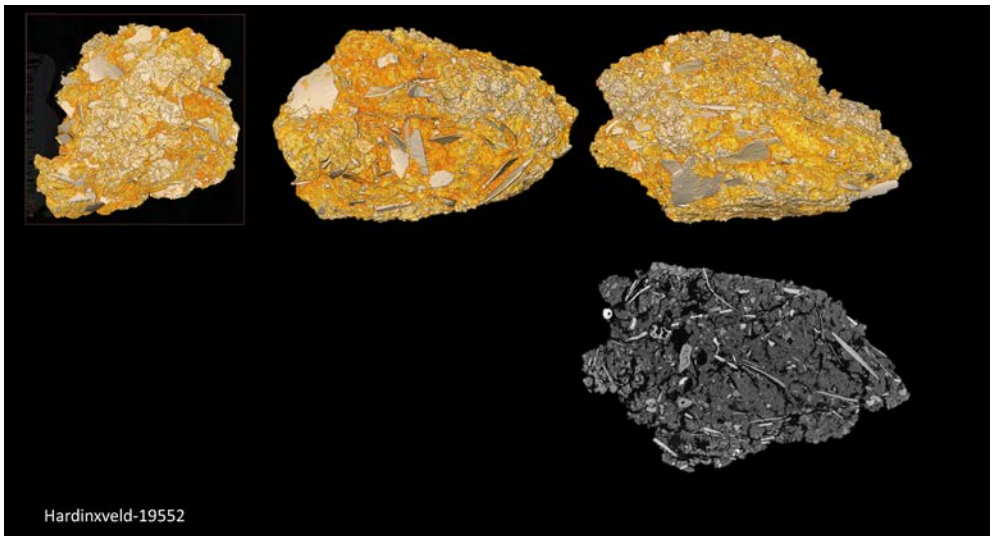


Figure IV.3 Coprolite Hardinxveld 19952. Volume rendering of coprolite volume and vertical micro-CT scan slice.

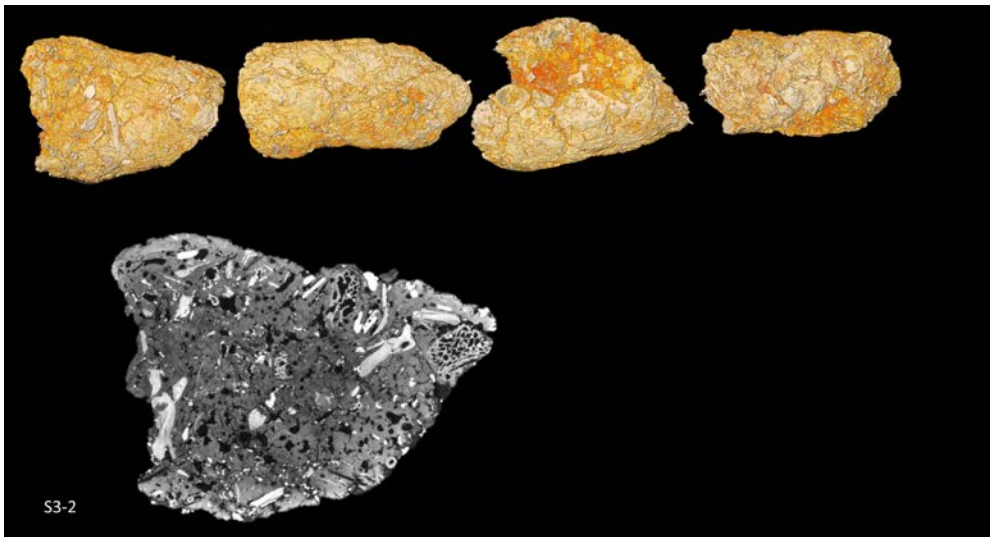


Figure IV.4.Coprolite S3-2 .Volume rendering of coprolite volume and vertical micro-CT scan slice.

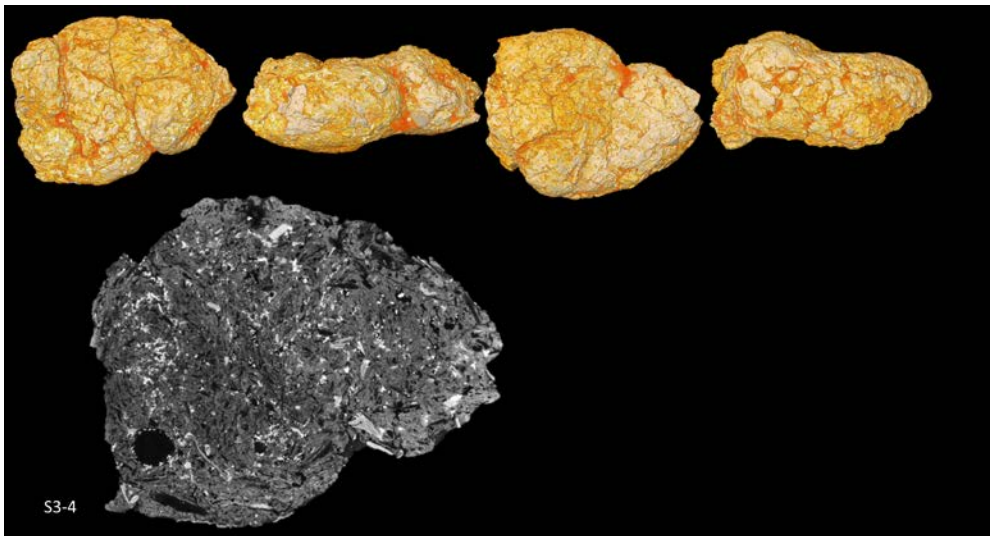


Figure IV.5 Coprolite S3-4.Volume rendering of coprolite volume and vertical micro-CT scan slice.

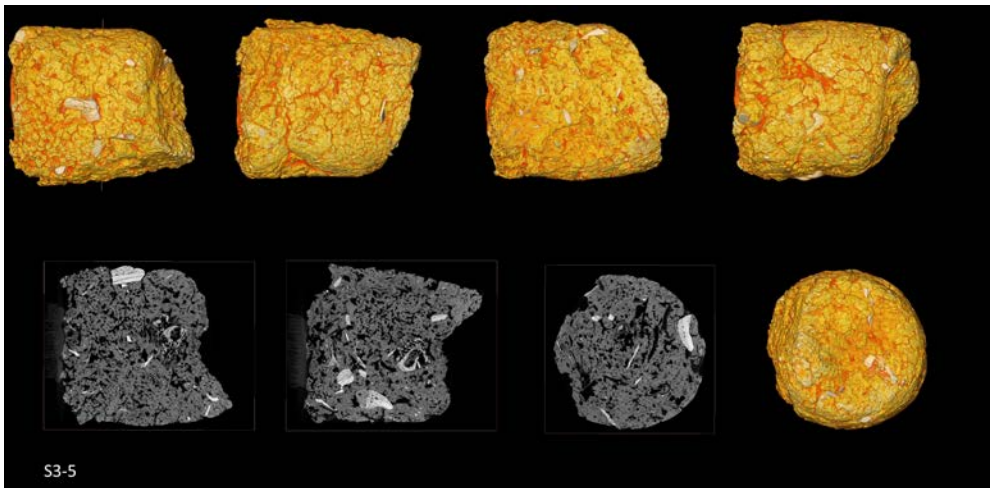


Figure IV.6 Coprolite S3-5.Volume rendering of coprolite volume and vertical micro-CT scan slice.

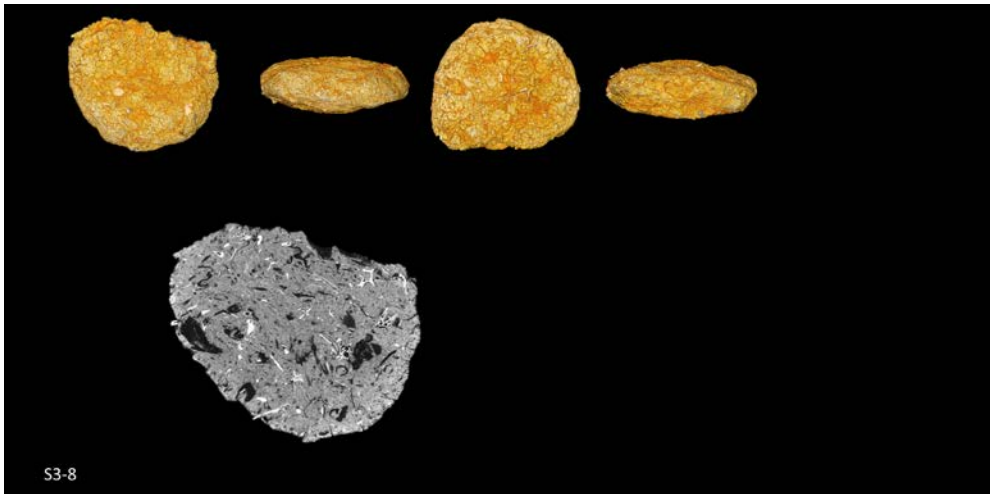


Figure IV.7 Coprolite S3-8.Volume rendering of coprolite volume and vertical micro-CT scan slice.

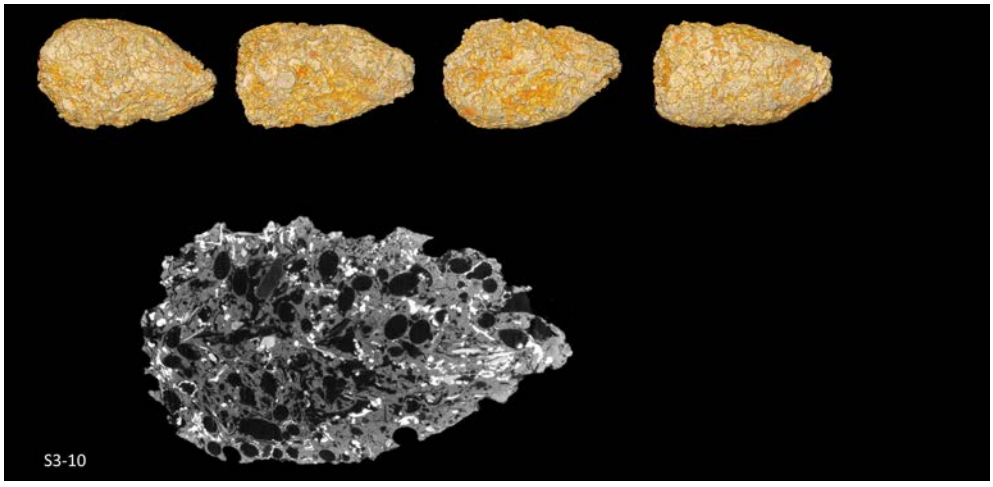


Figure IV.8 Coprolite S3-10.Volume rendering of coprolite volume and vertical micro-CT scan slice.

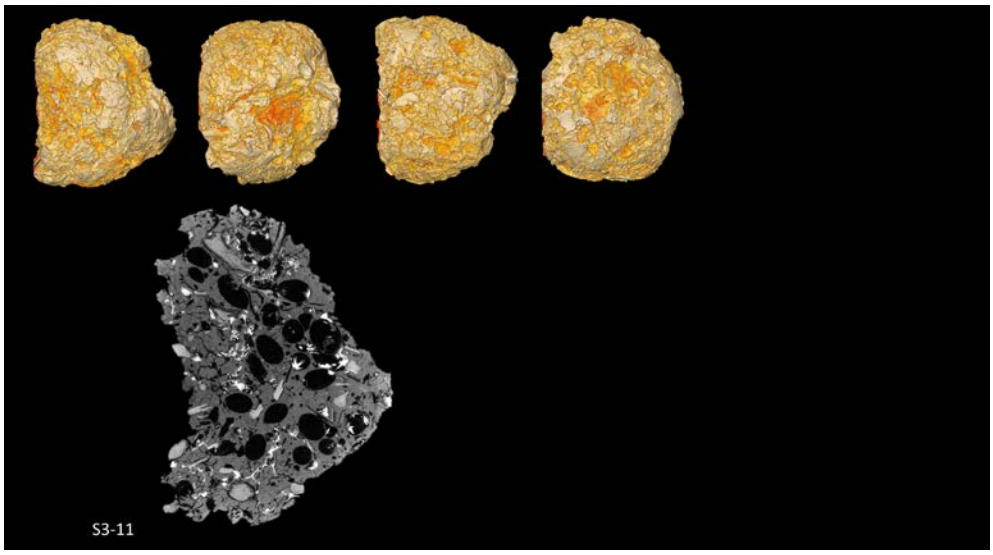


Figure IV.9 Coprolite S3-11.Volume rendering of coprolite volume and vertical micro-CT scan slice.

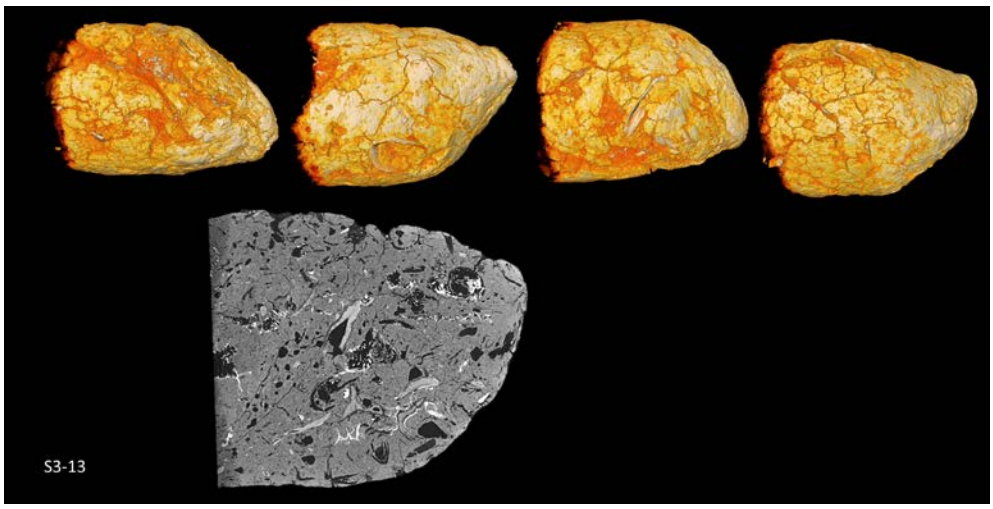


Figure IV.10 Coprolite S3-13.Volume rendering of coprolite volume and vertical micro-CT scan slice.

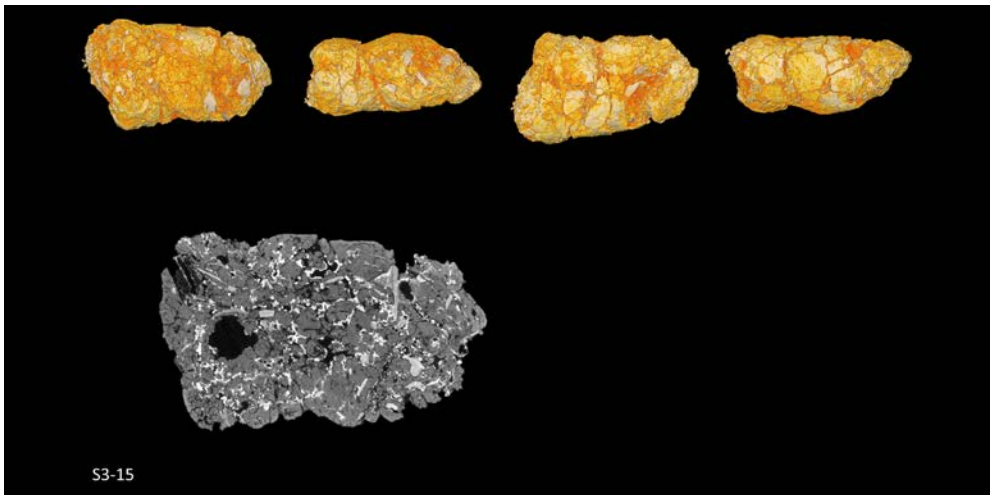


Figure IV.11 Coprolite S3-15.Volume rendering of coprolite volume and vertical micro-CT scan slice.

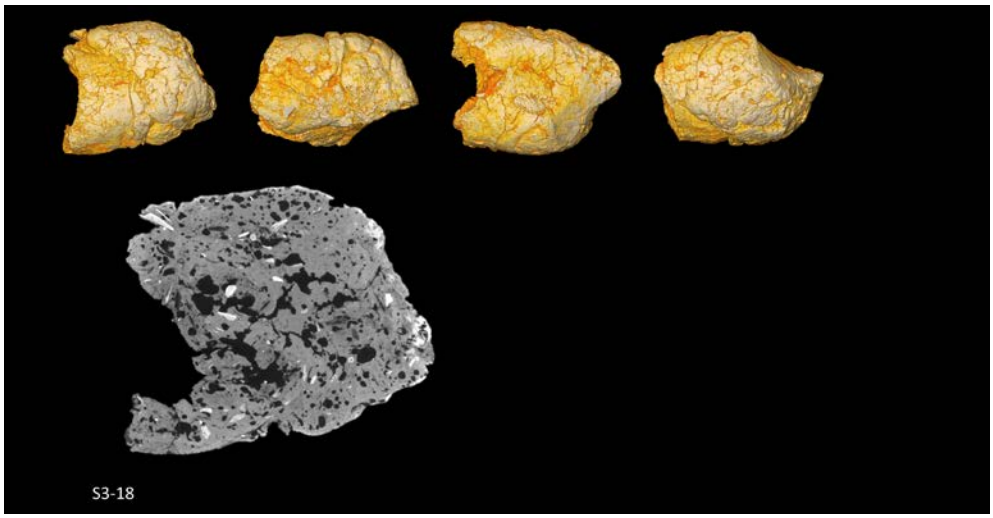


Figure IV.12 Coprolite S3-18. Volume rendering of coprolite volume and vertical micro-CT scan slice.

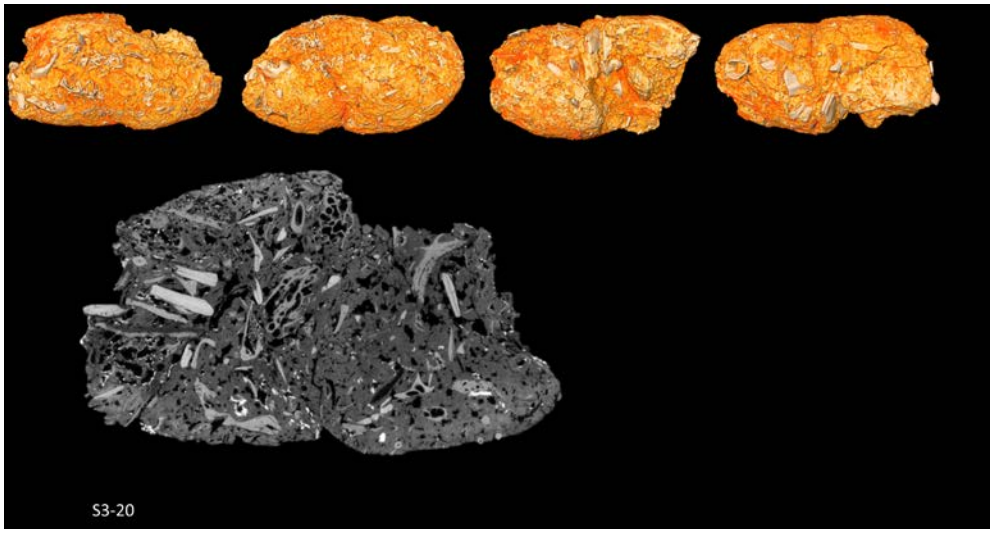


Figure IV.13 Coprolite S3-20. Volume rendering of coprolite volume and vertical micro-CT scan slice.

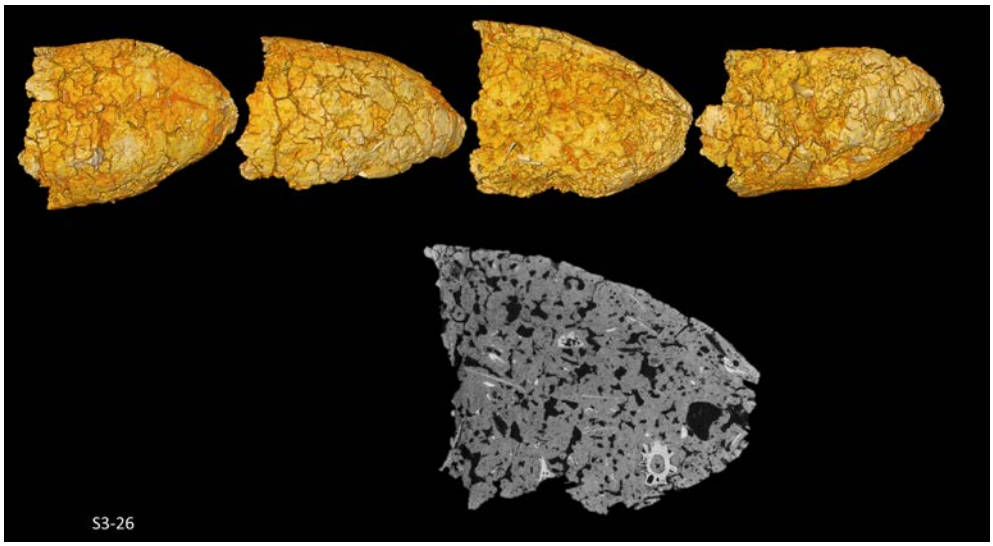


Figure IV.14. Coprolite S3-26. Volume rendering of coprolite volume and vertical micro-CT scan slice.

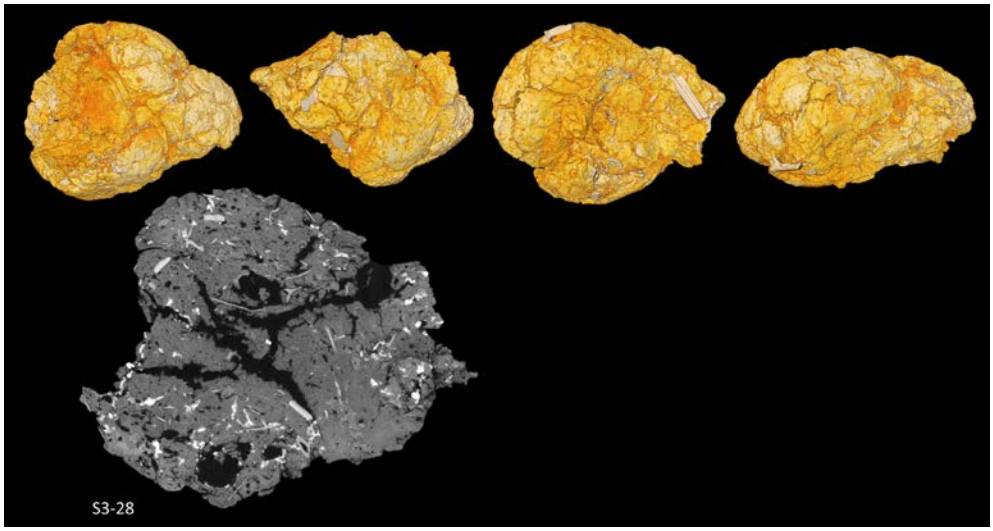


Figure IV.15 Coprolite S3-28.Volume rendering of coprolite volume and vertical micro-CT scan slice.

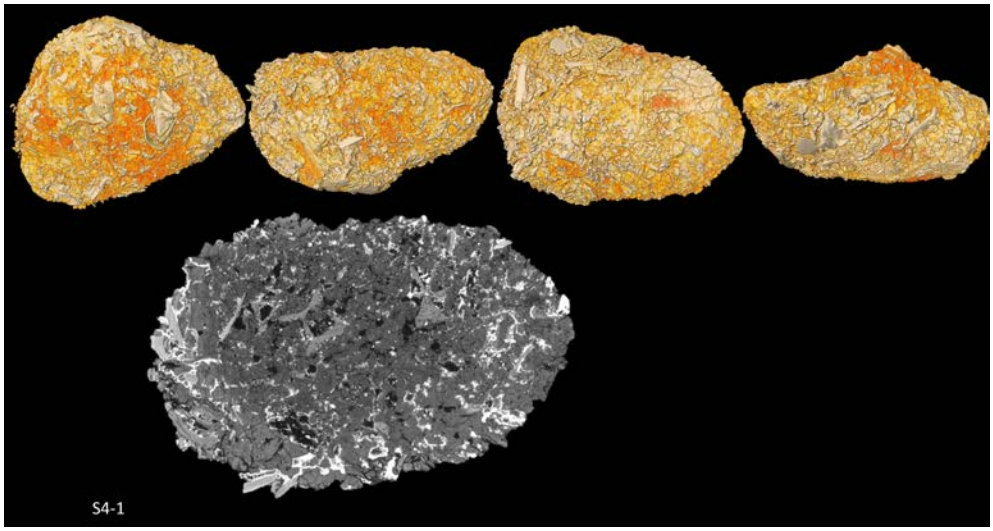


Figure IV.16 Coprolite S4-1.Volume rendering of coprolite volume and vertical micro-CT scan slice.

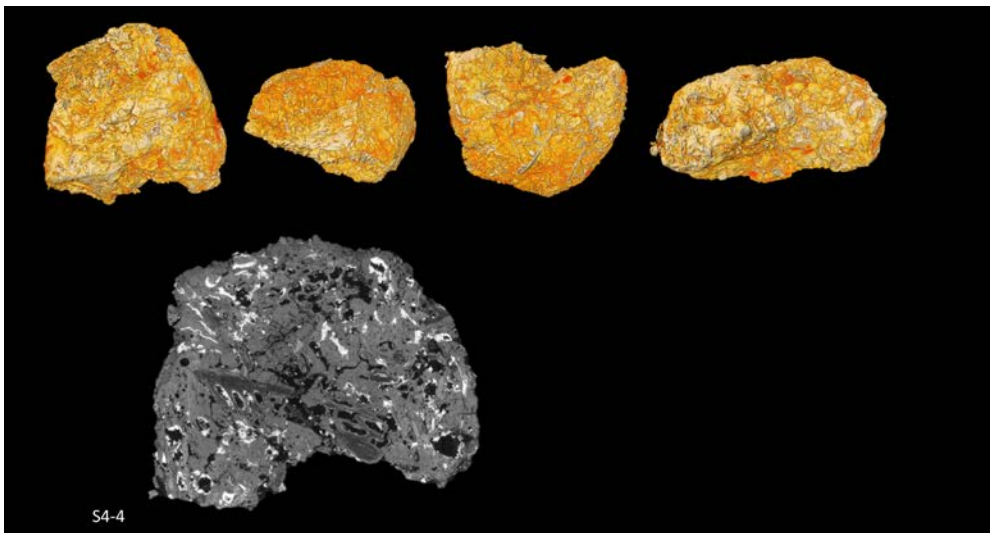


Figure IV.17 Coprolite S4-4.Volume rendering of coprolite volume and vertical micro-CT scan slice.

V Micro-CT scans 3: Inventory of bones per coprolite (Chapter 6)

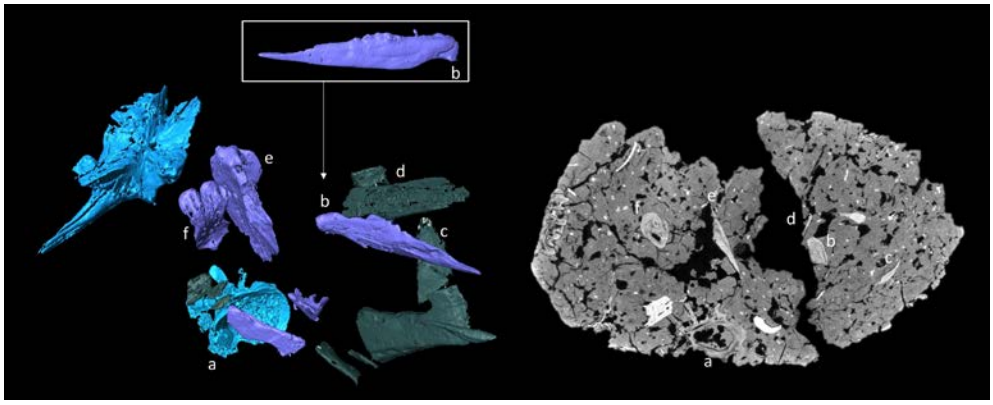


Figure V.1 Hardinxveld 19520, scan 0.035 mm voxel. Only a few bones have been extracted: vertebras (blue) like a, 14.6 mm long perch dental (b), c: scale, and other large bones with a specific shape (d-f).

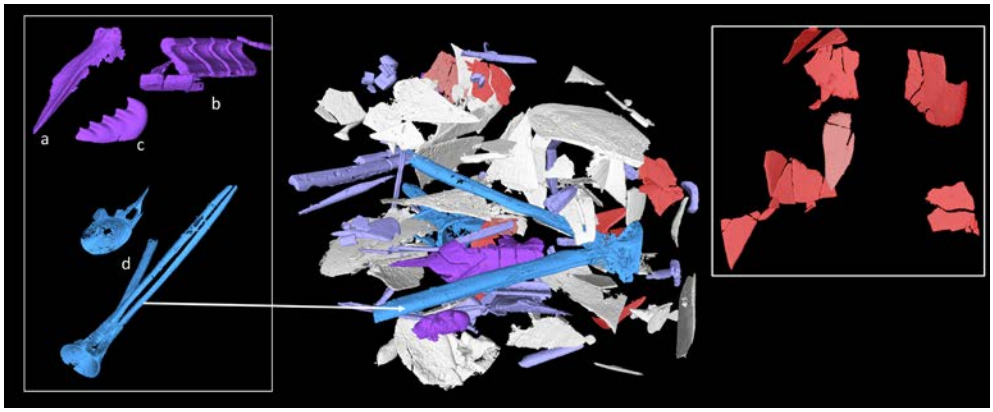


Figure V.2 Hardinxveld 19952, scan 0.008 mm voxel. Very large number of scales (white and red), 2 vertebras (blue) and many other bones (bright and pale violet). Several bones are fractured. The right insert show examples of fractured scales. a: possible spike, b: series of articulated plates, c: jaw bone, d: vertebras.

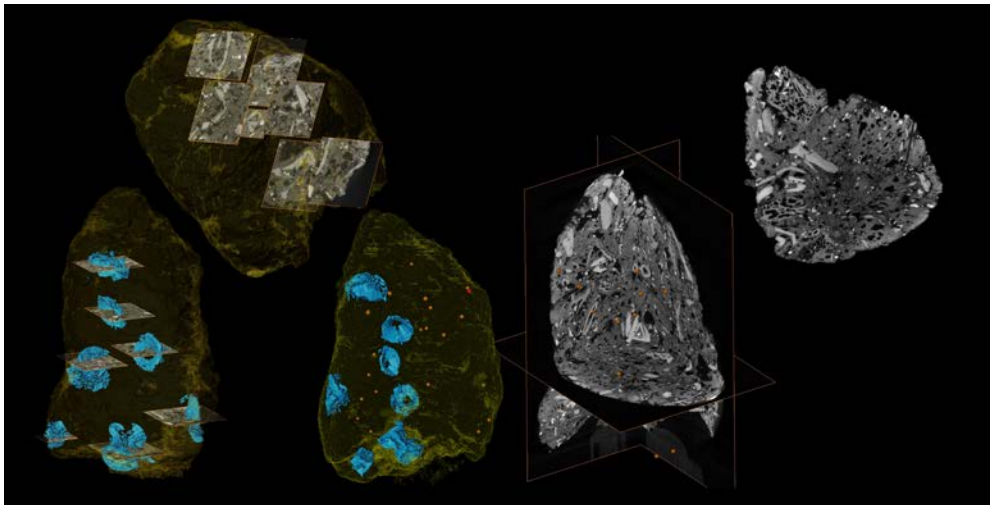


Figure V.3 S3-2, scan 0.040 mm voxel. Distribution of vertebras and pike teeth in coprolite S3-2. Orange dots points at teeth. Note also the large 4 to 5 mm high cavernous bones (right).

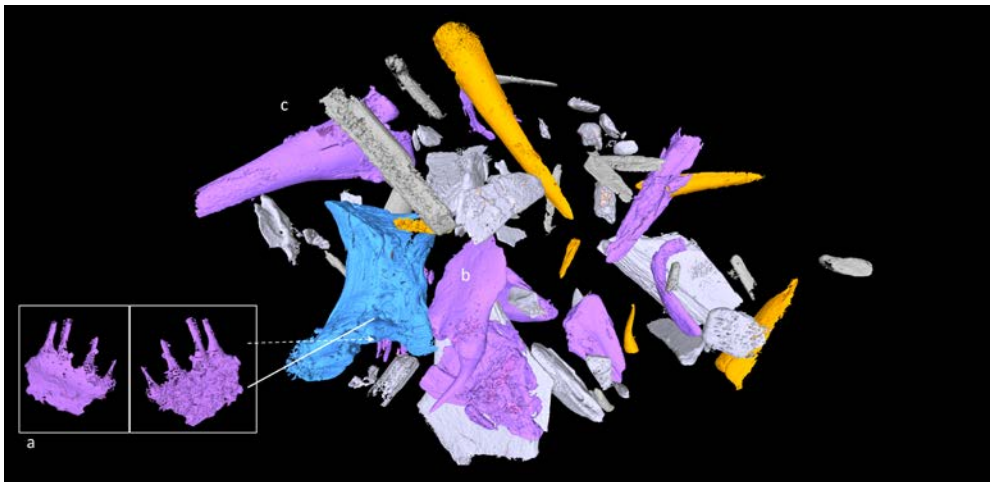


Figure V.4 S3-2, sub-scan 0.011 mm voxel. Bones contained in a sub-sample occupying 4 % of the total volume of coprolite S3-2. Among others, bones with a specific shape (violet), many pike teeth (orange), a vertebra fragment (blue) barely identified in the scan of the whole coprolite, and many platy and/or elongated bones. a: palatinum with 5 teeth, verso & recto views. b: tooth on jaw fragment, c: pike tooth with split base.

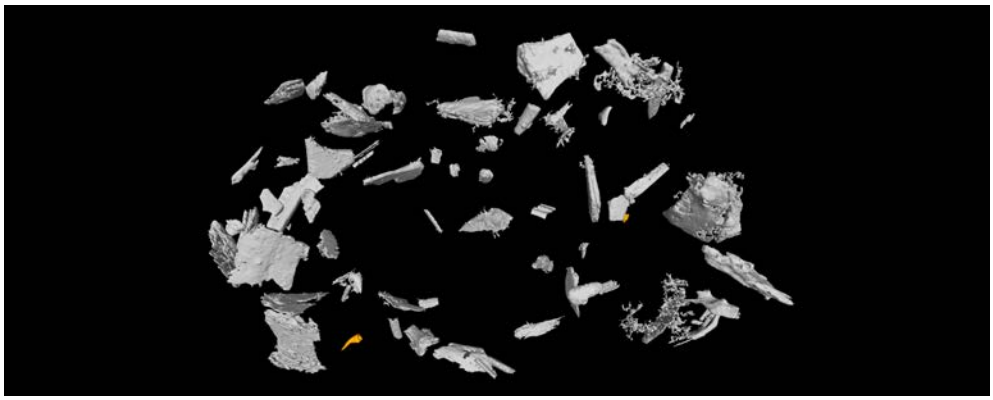


Figure V.5 S3-4, sub-scan 0.020 mm voxel. Only a few small teeth (orange), some scales (thin plates) and long bones plus a large group of unidentifiable small bone fragments.

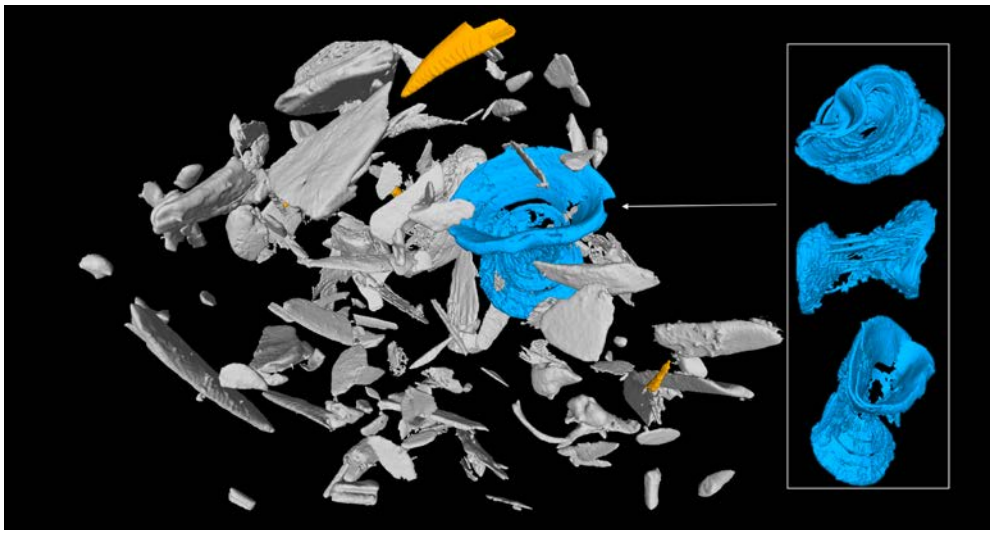


Figure V.6 S3-5, scan 0.025 mm voxel. Many bones, several teeth and vertebra fragments, and one 6.3 mm highly distorted complete vertebra.

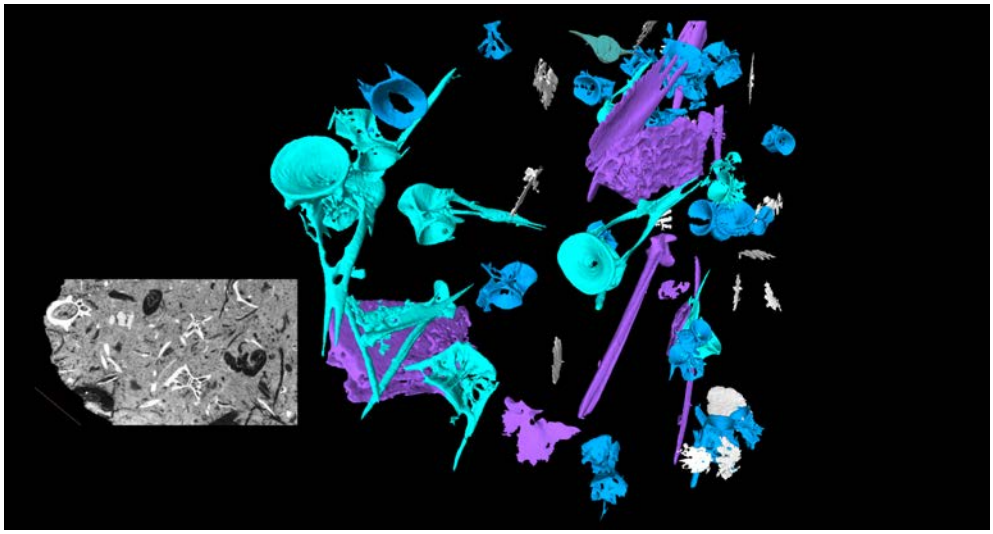


Figure V.7 S3-8, scan, 0.028 mm voxel. Many perch , 0.4 to 2.5 mm high vertebras (blue), many of them still connected to one of their spines (turquoise). The longest spines are about 6 mm long. Note the well preserved scaffolding inner structure of the vertebras (grey slice).

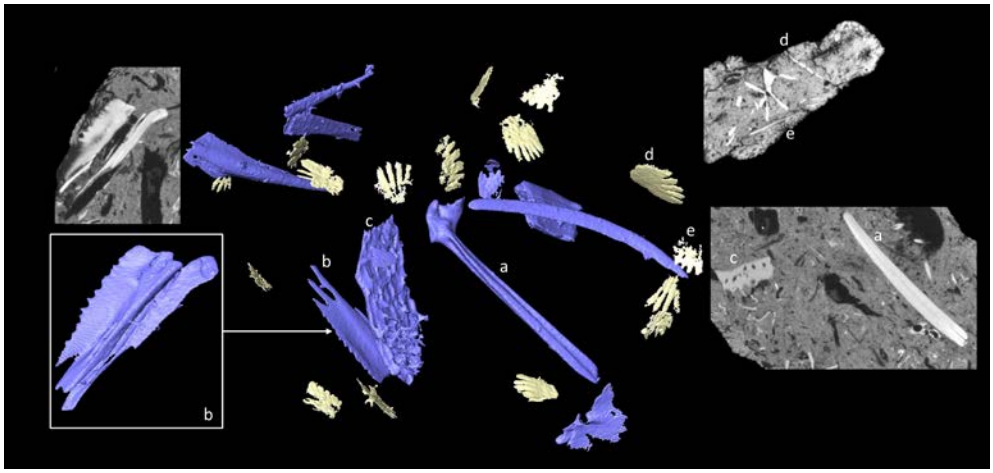


Figure V.8 S3-8, 0.028 mm voxel. Also many about 2.8 mm high perch scales (white), a detached 11.8 mm long spine, (a) and a 6.5 mm long bone with saw teeth edge (b). Note the differences in inner bone structure on grey slices.

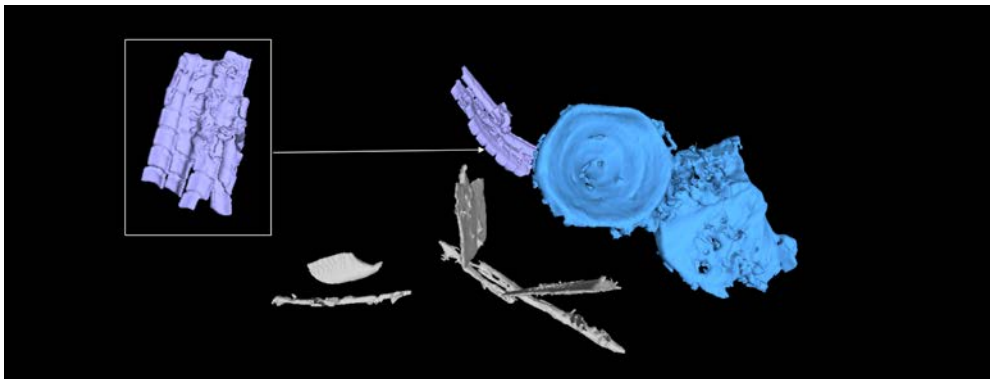


Figure V.9 S3-10, scan 0.040 mm voxel. Two degraded half vertebras (blue), a large segmented distal finray (violet), a scale, and a few more bones.

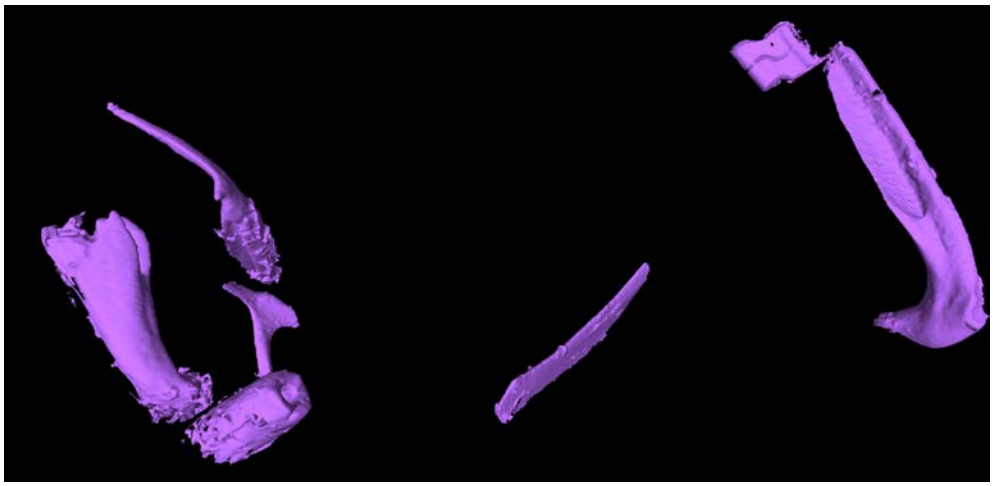


Figure V.10 S3-11, scan 0.025 mm voxel. Only a few bones have been extracted. The coprolite contains many vertebra fragments too.

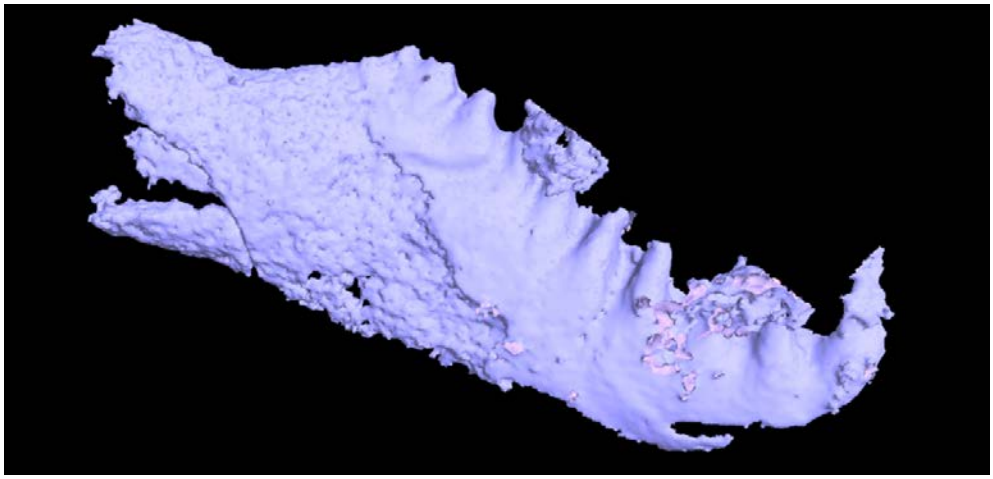


Figure V.11 S3-13, sub-scan 0.024 mm voxel. Fish jaw bone (8.2 mm long); other bones, including vertebras not separated.

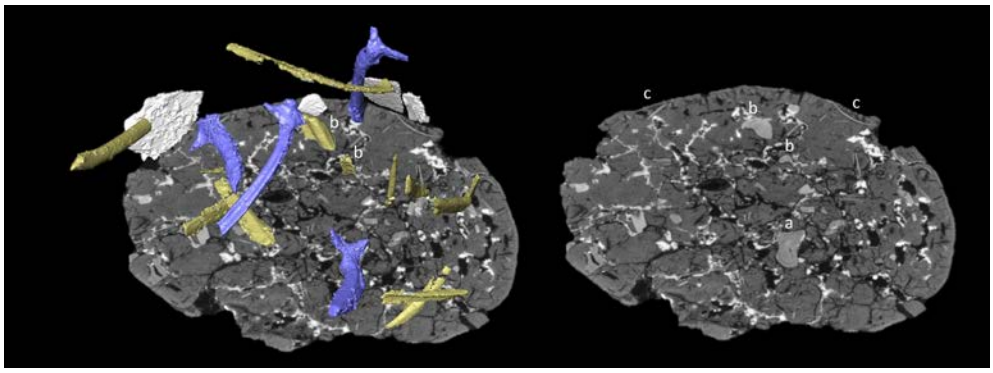


Figure V.12 S3-15, scan 0.040 mm voxel. About 9 mm long pike spines (purple, a), a few U-tube fin bone elements (b), several scales (c), plus many unidentified long (yellow) or platy (white) fish bones.

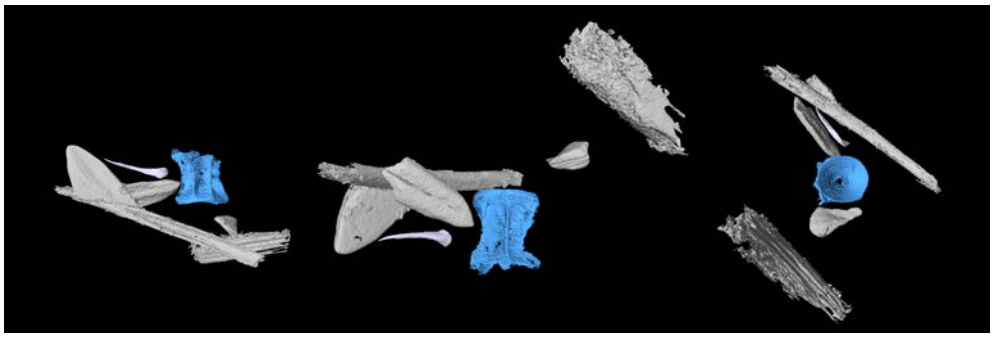


Figure V.13 S3-15, sub-scan 0.011 mm voxel. Zoom on a 2.3 mm high vertebra surrounded by platy bones and a small curved tooth seen under different angles. 5 spikes have also been found.

Figure V.14 S3-18, sub-scan 0.009 mm voxel. One incomplete, 2.1 mm diam. vertebra (blue), several pike teeth (orange) and other bones (white), including scales. a is a 3.7 mm long pike tooth. Three of the pike teeth have been scanned individually.

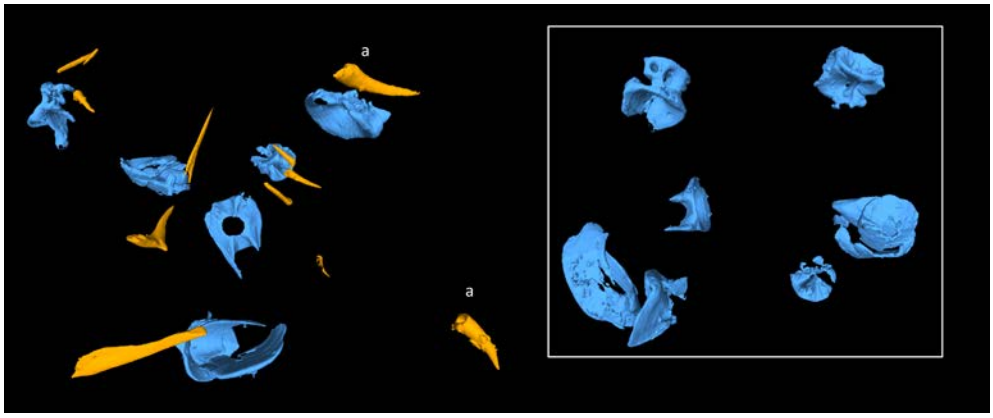


Figure V.15 S3-20, sub-scan 0.010 mm voxel. 6 vertebras (blue) and pointed bones (orange); among them, several pike teeth (a). The verso side of the 6 vertebras is framed on the right; the top right vertebra belongs to a cyprinid fish.

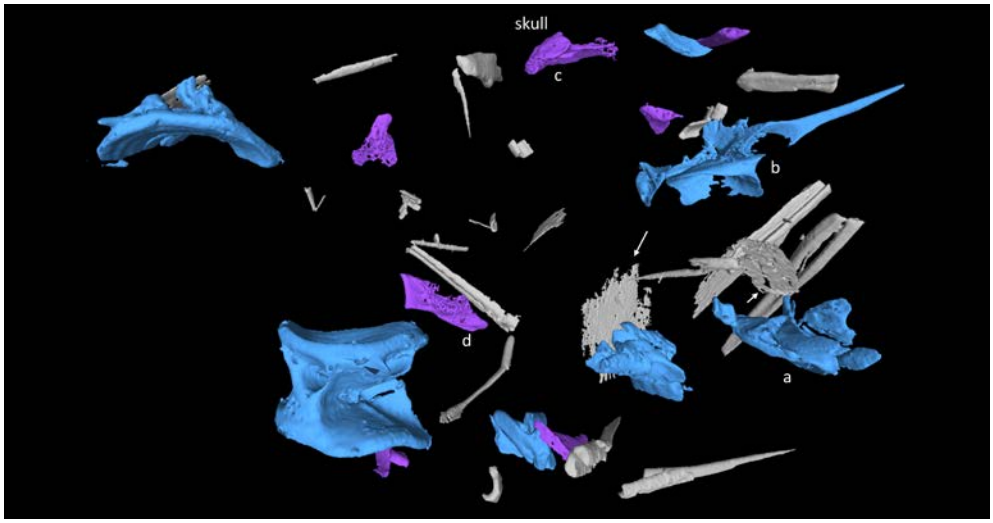


Figure V.16 S3-26, scan 0.028 mm voxel. 7 complete or fragmented vertebra (blue), the bottom left being a pike vertebra, special shape bones (violet), and other fish bone fragments, including scales (white arrows). Numerous scales visible in scan. See zooms in next figure.

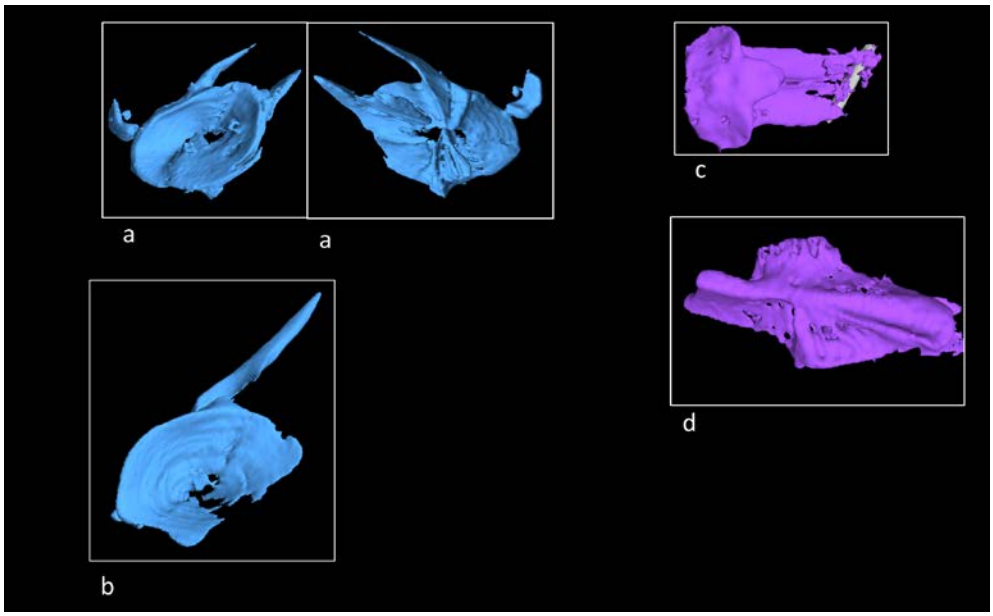


Figure V.17 S3-26, scan 0.028 mm voxel. a and b: Zoom on two vertebras (recto and verso), c and d: skull.

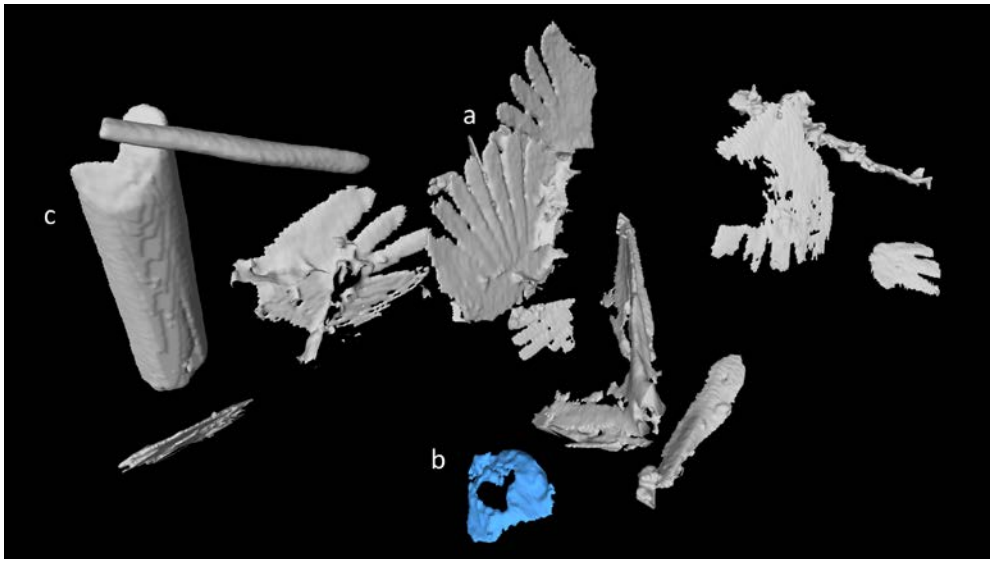


Figure V.18 S3-28, scan 0.032mm voxel. Several waving hand-like perch scales (a), one damaged vertebra (b) and possible u-tube fin (c). Not shown here: many more perch scales, several vertebra fragments, a spine and one pointed hollow conical bone too straight to be a pike tooth.

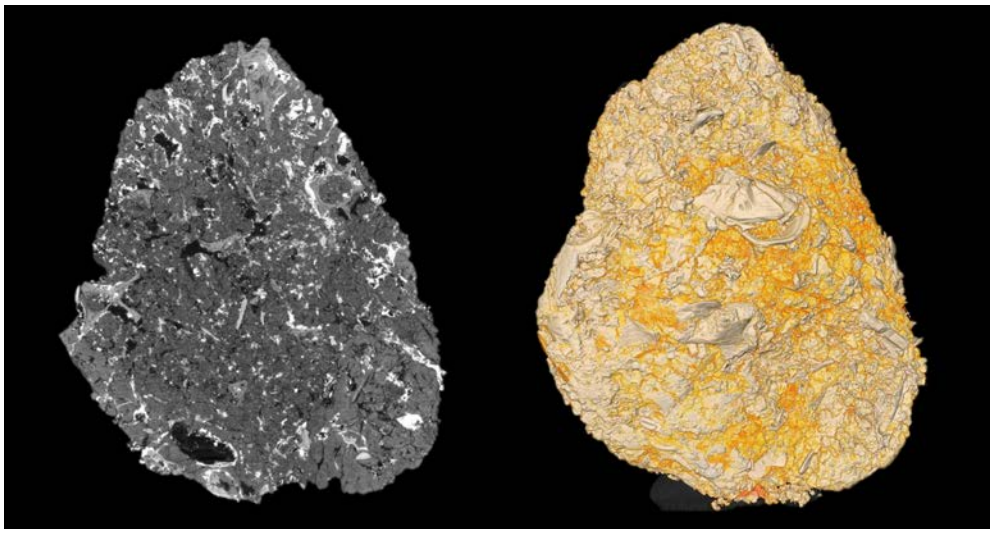


Figure V.19 S4-1, scan 0.028mm voxel. Many vertebras, not yet separated!

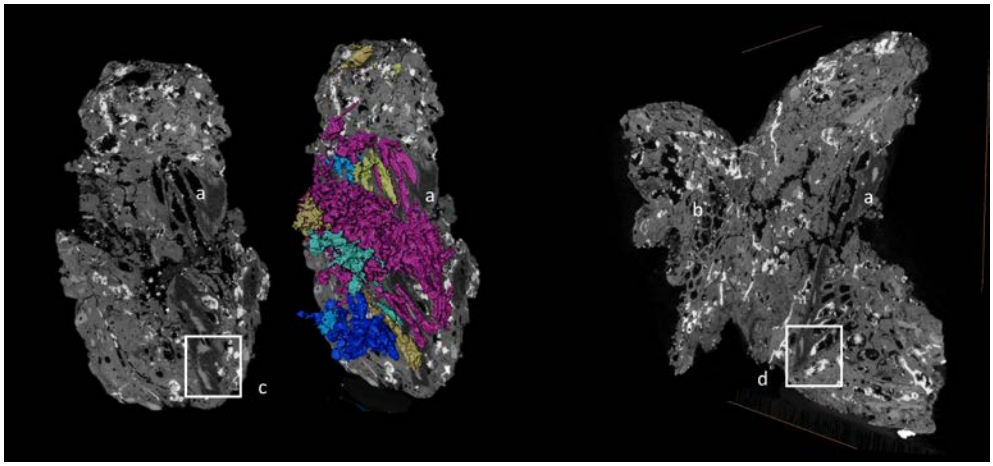


Figure V.20 S4-4, scan 0.025mm voxel. Large cavernous bones with elongated cavities. a, 17 mm long, b, 12 mm long. Note the variable X-ray attenuation values of these bone tissues and their gypsum mineralisation (c and d).

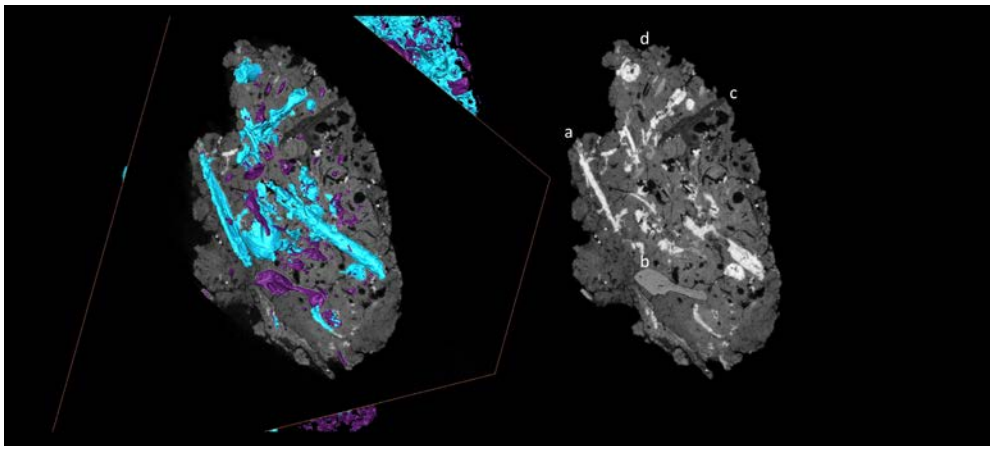


Figure V.21 S4-4, scan 0.025mm voxel. The challenge of segmenting bones in S4-4. a: elongated (bone and/or plant) tissues fully mineralized (blue), b, bone attenuating X-ray more than the matrix (violet), and c, less than the matrix. d might be a mineralised rolled plant tissue.

VI Micro-CT scans 4: Inventory of voids per coprolite (Chapter 6)

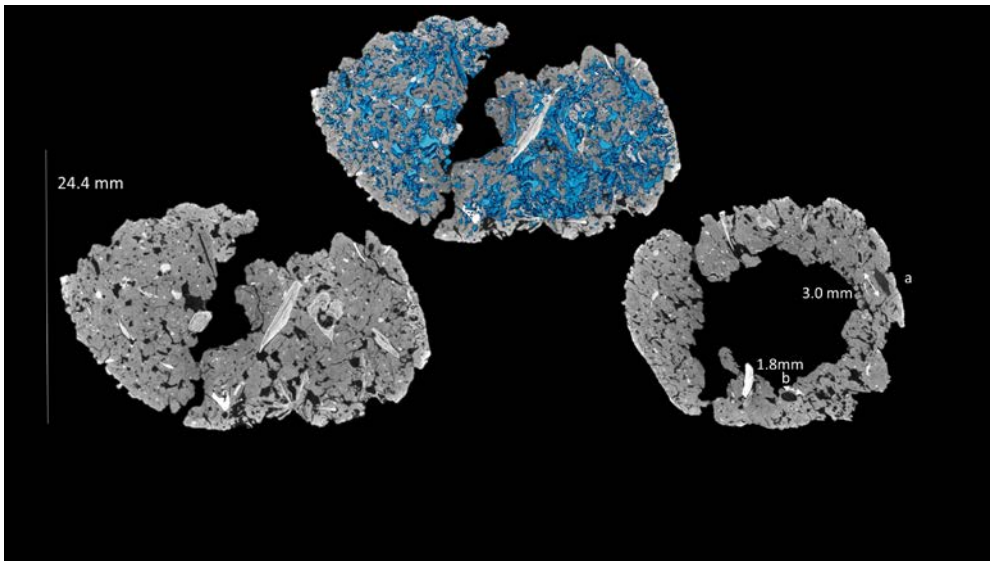


Figure VI.1 Hardinxveld 19520. scan 0.035 mm voxel. Polygonal desiccation cracks connected to (unidentified) non spherical voids with compact amorphous matrix. A few dark inclusions, possibly charred tissues can be discerned (a and b).

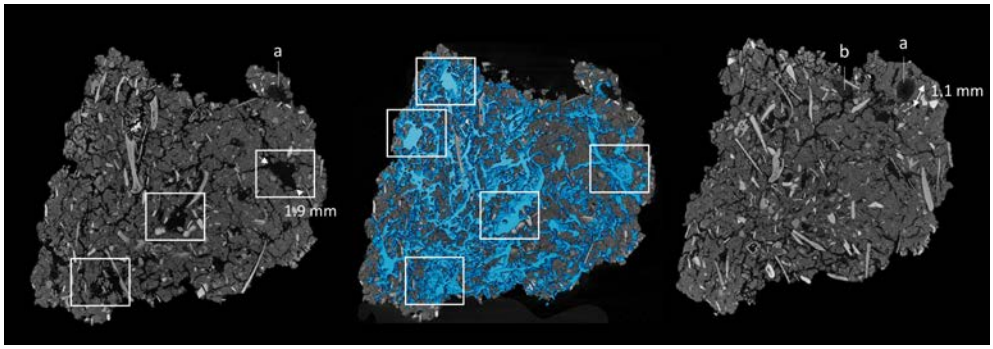


Figure VI.2 Hardinxveld 19952, scan 0.016 mm voxel. Polygonal desiccation cracks, some following bones and connected to large (unidentified) voids marked with white squares. A few dark inclusions, probably charred tissues can be discerned (a and b).

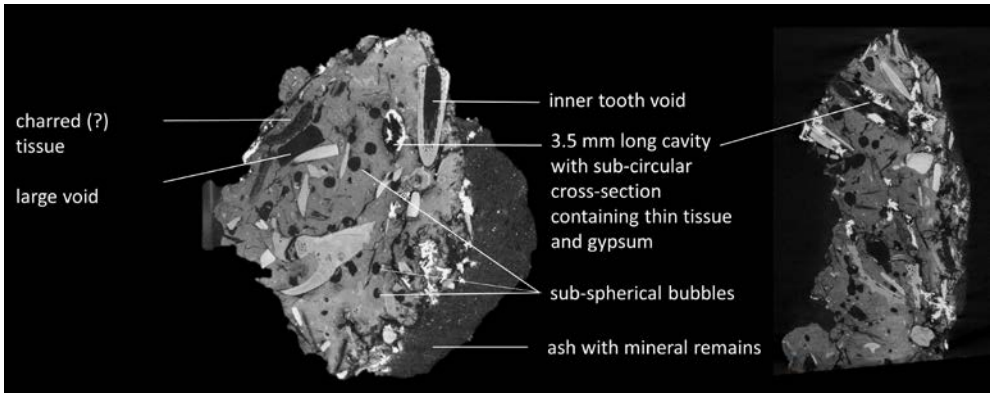


Figure VI.3 S3-2, sub-scan 0.011 mm voxel. Various low attenuating features.

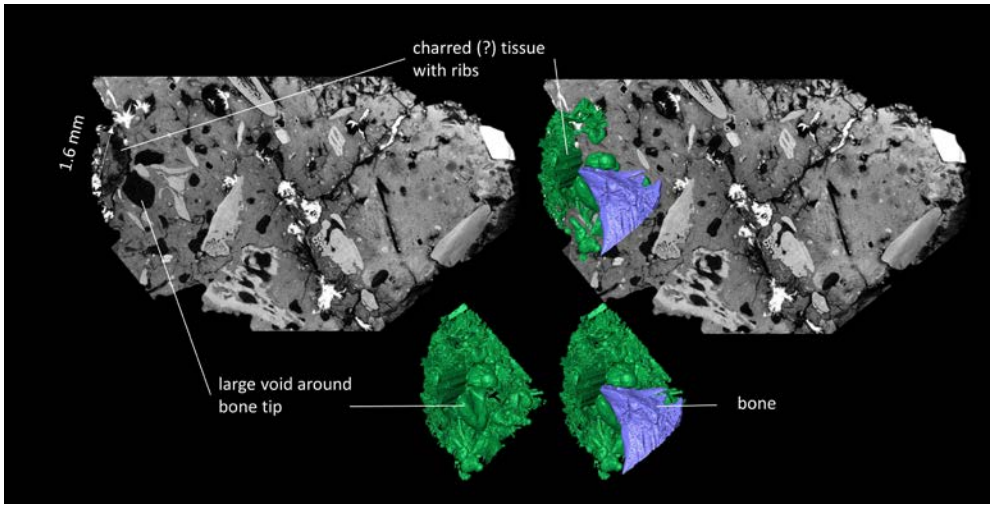


Figure VI.4 S3-2, sub-scan 0.011 mm voxel. 3D representation of likely charred tissue with ribs and large bone encapsulating bone tip.

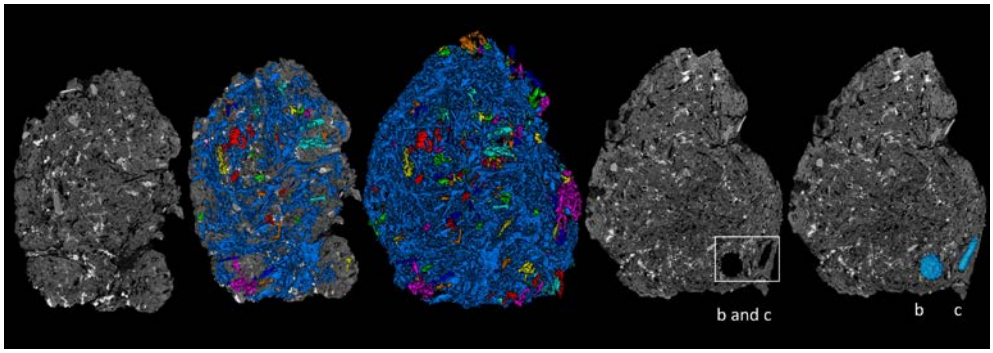


Figure VI.5 S3-4, scan 0.035 mm voxel. Very dense network of elongated voids with a few unidentified voids (a, b, and c), some (b and c) with a specific shape. b, 3.5 mm diameter sphere and c, 4.6 mm long stick.

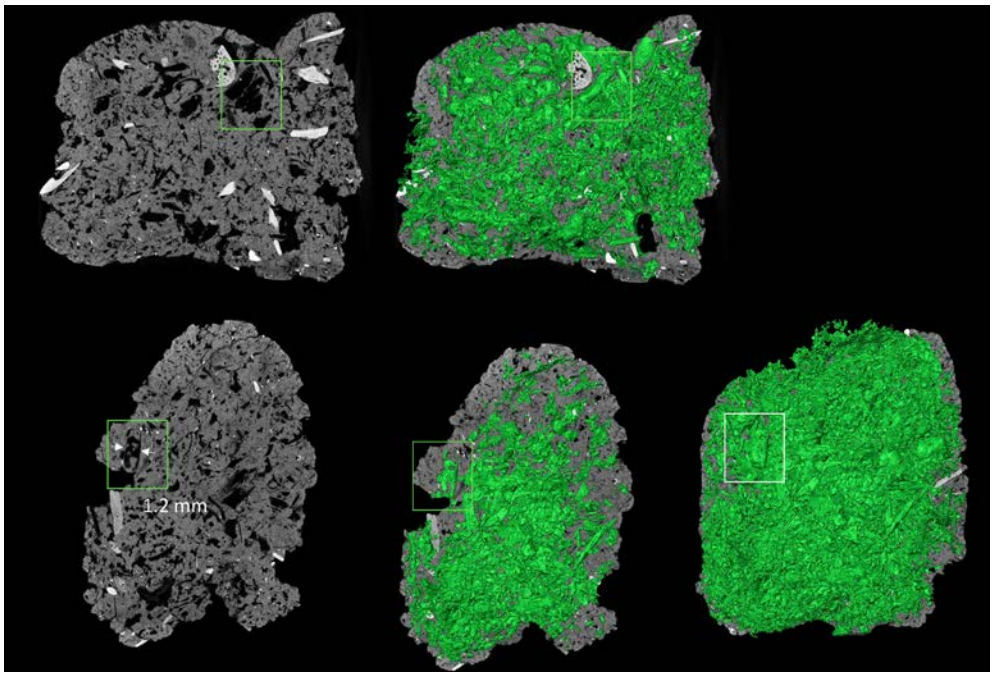


Figure VI.6 S3-5, scan 0.025 mm voxel. Dense network of thin elongated voids with many large stem like plant voids.

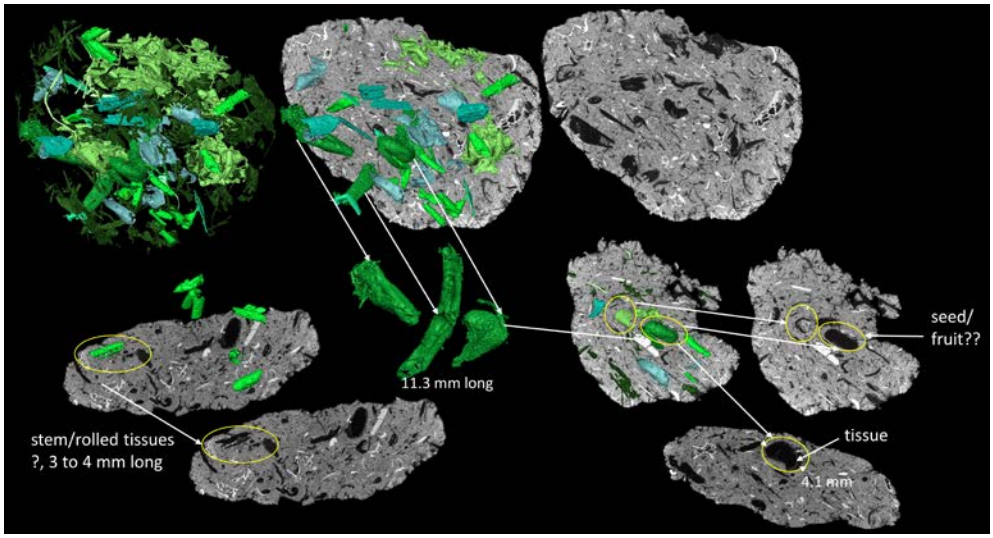


Figure VI.7 S3-8, scan 28 mm voxel. Cake-like coprolite. Many thin elongated voids and large voids with distinct shape, possible phantoms of rolled tissues, plant tissues with ribs and rounded seed fragment.

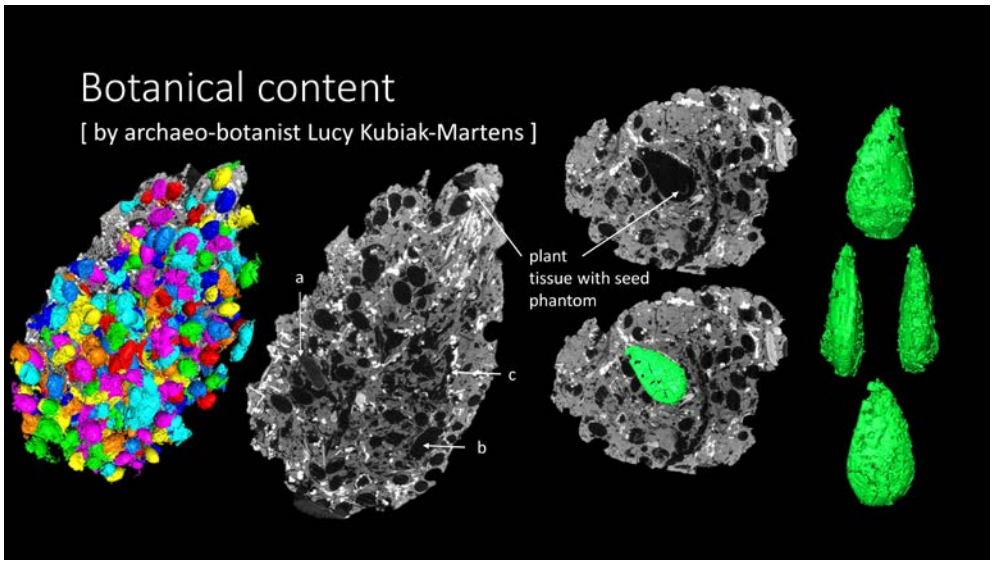


Figure VI.8 S3-10, scan 0.040 mm voxel. Hundreds of phantoms of white water lily seeds (2.3 to 3.3 mm long) and one phantom apple seed (green, 8.5 mm high) plus a few large unidentified tissues (a) and large voids (b and c).

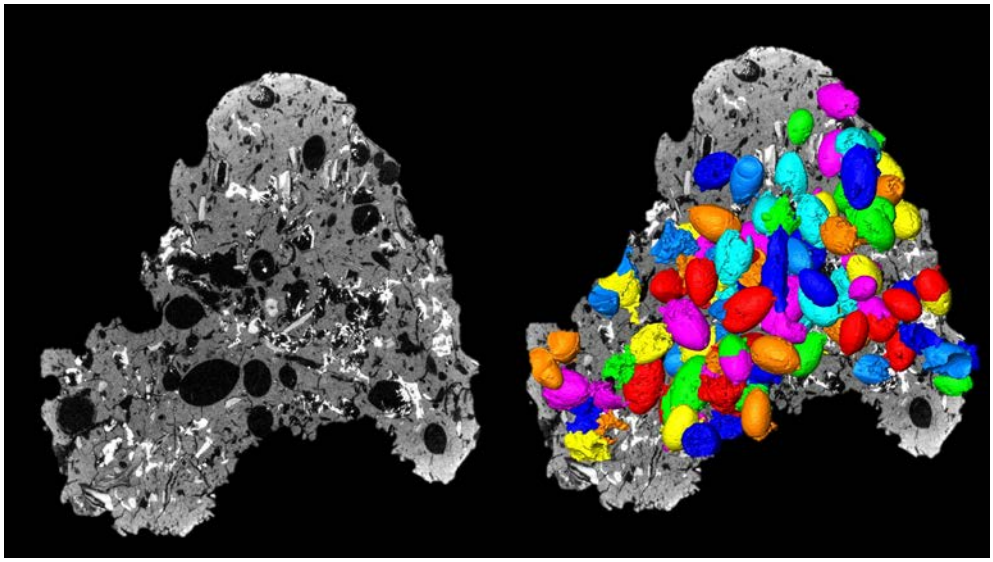


Figure VI.9 S3-11, scan 0.025 mm voxel. Large number of white lily seeds, 2.3 to 3.3 mm long. Fine grained matrix, crack pattern, and small bone fragments content resembling that of S3-10. Some remaining water lily tissues can be discerned on the grey slice, some enveloping the phantom.

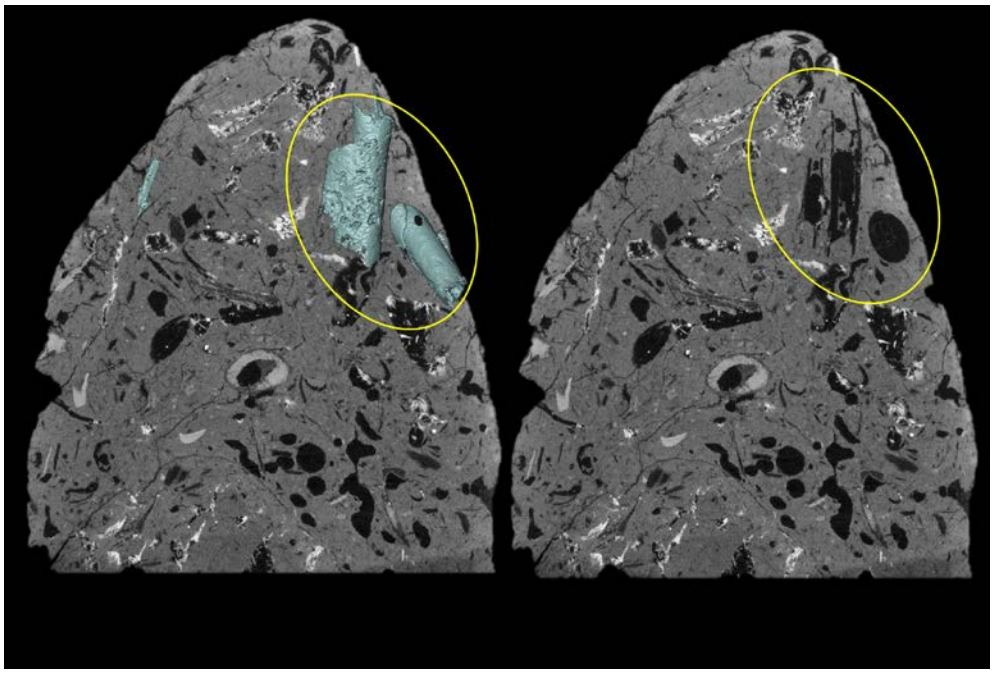


Figure VI.10 S3-13, scan 0.024 mm voxel. Long rolled plant tissues plus sub-rounded bubbles within a fine grained matrix crossed by thin cracks.

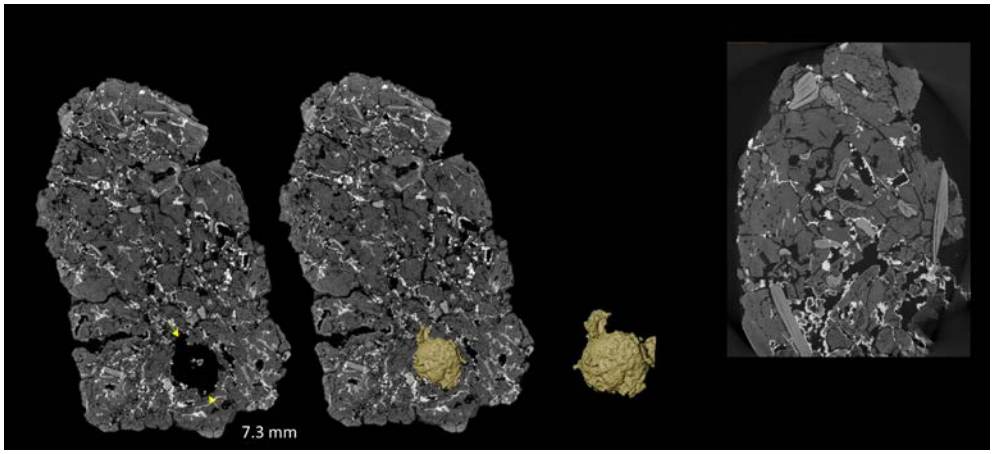


Figure VI.11 S3-15, scan 0.040 and sub-scan 11 mm voxel. Left, one large spherical inclusion within a matrix crossed by mineralised desiccation cracks. Right, detail of porous network (image 12 mm wide).

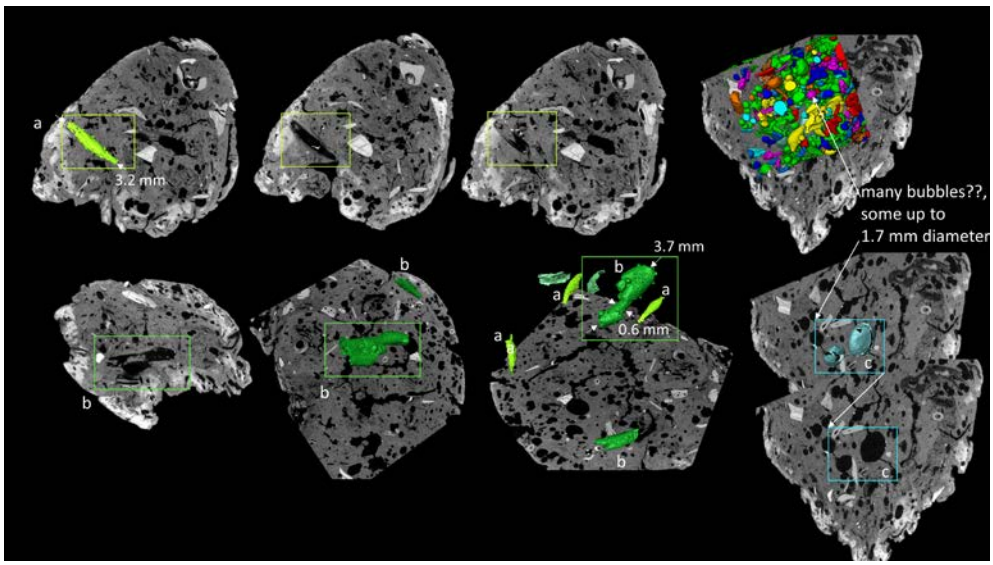


Figure VI.12 S3-18, sub-scan 0.009 mm voxel. Possible chaff fragments (a), 2.7 to 3.2 mm long, large stem like / rolled imprints with tissue, 3.7 mm long (b), and possible small and large bubbles (c) in a fine grained matrix.

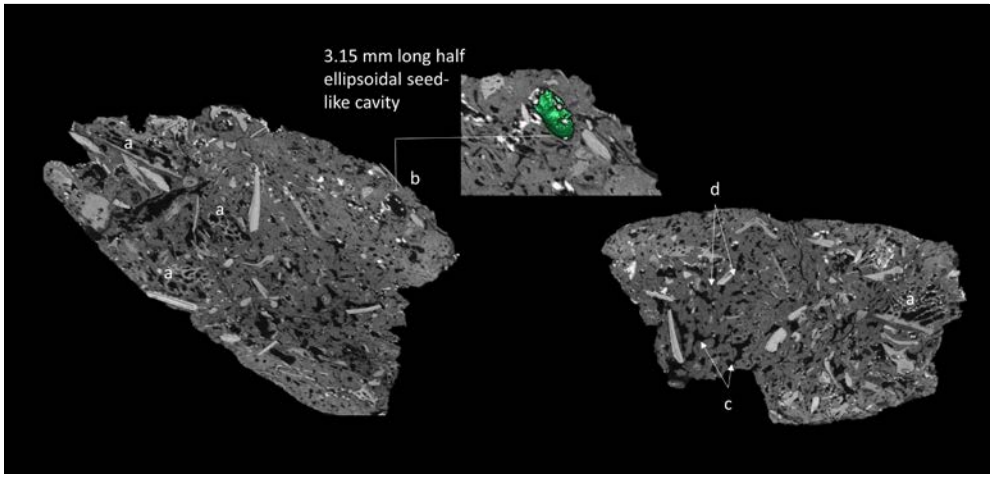


Figure VI.13 S3-20, scan 0.040 mm voxel. The large cavities (a) of the many large spongy bones present in S3-20 complicate the detection of seed-like phantom (b). Note the presence of many non-spherical voids (c) and thin polygonal cracks (d) in the matrix of S3-20.

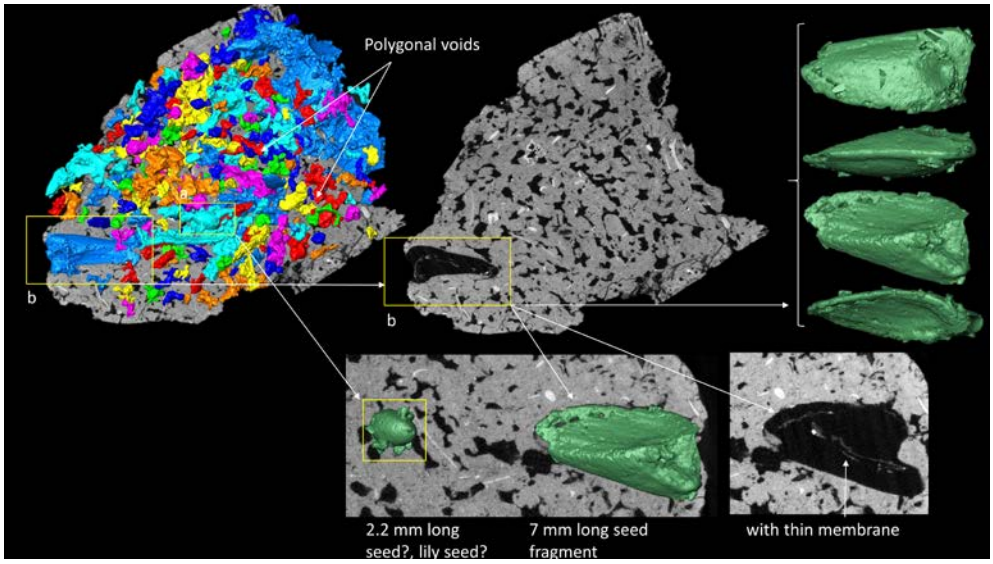


Figure VI.14 S3-26, scan 0.028 mm voxel. Many polygonal shaped voids and a few very large voids with a distinctive shape; one ellipsoidal void resembling the phantom of a lily seed (a) and a tri-facet void (b), which has yet to be identified. Note the thin membrane contained in b.

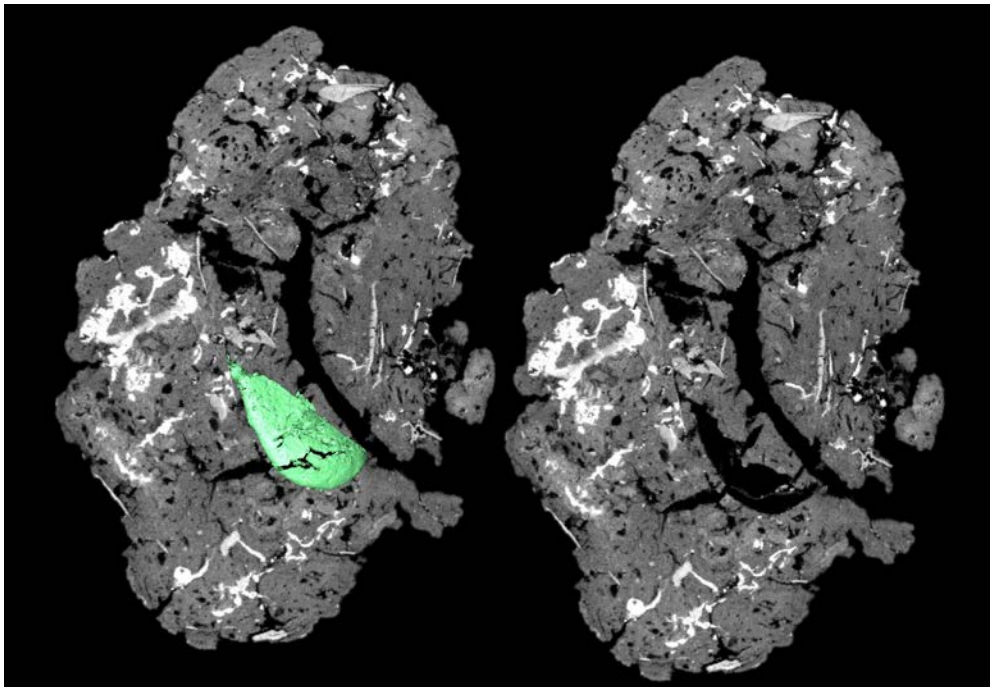


Figure VI.15 S3-28, scan 0.032mm voxel. 3D-reconstruction (left) and imprint (right) of one of the three apple seed phantoms found in S3-28. Note on the grey slice the thin membrane tissue contained in the phantom.

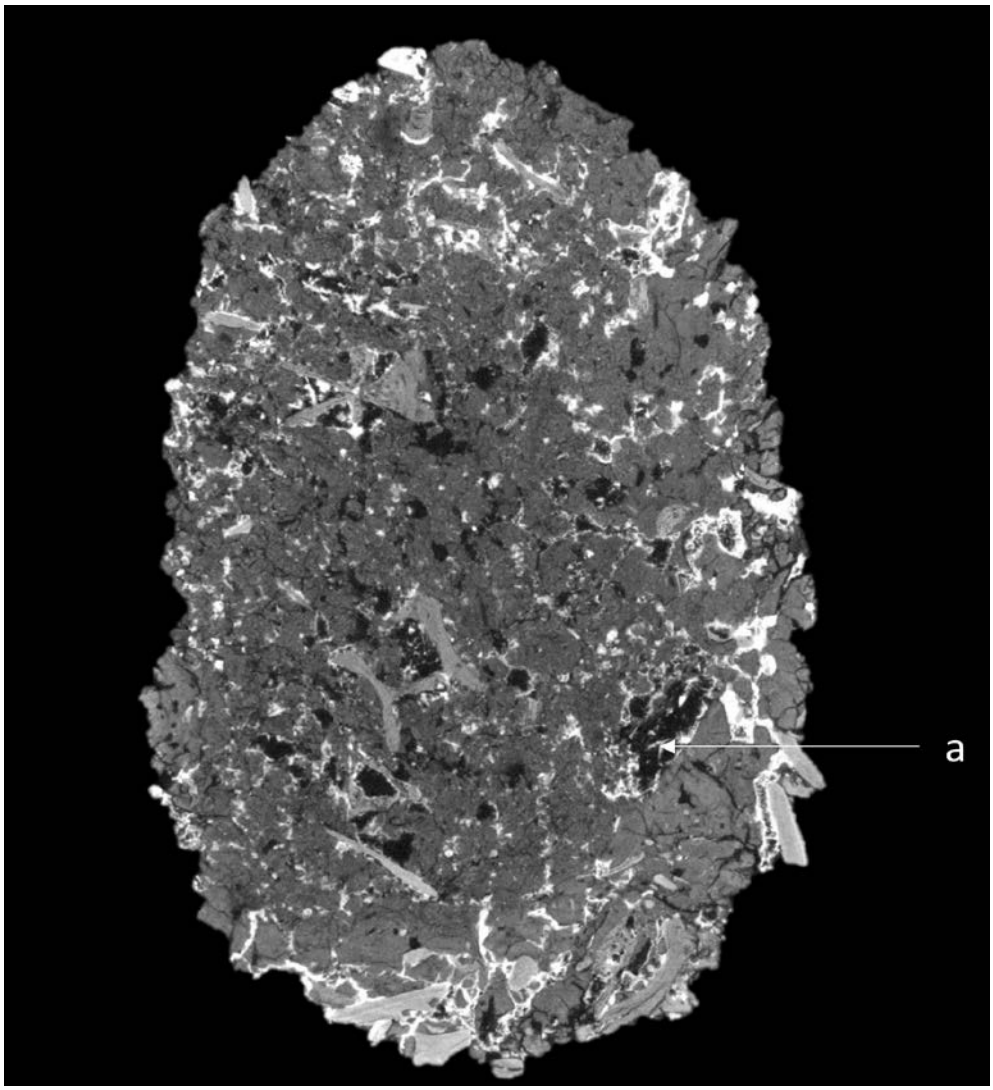


Figure VI.16 S4-1, scan 0.028 mm voxel. Vertical grey slice. Note the voids adjacent to the vertebras and the low attenuating tissue (a).

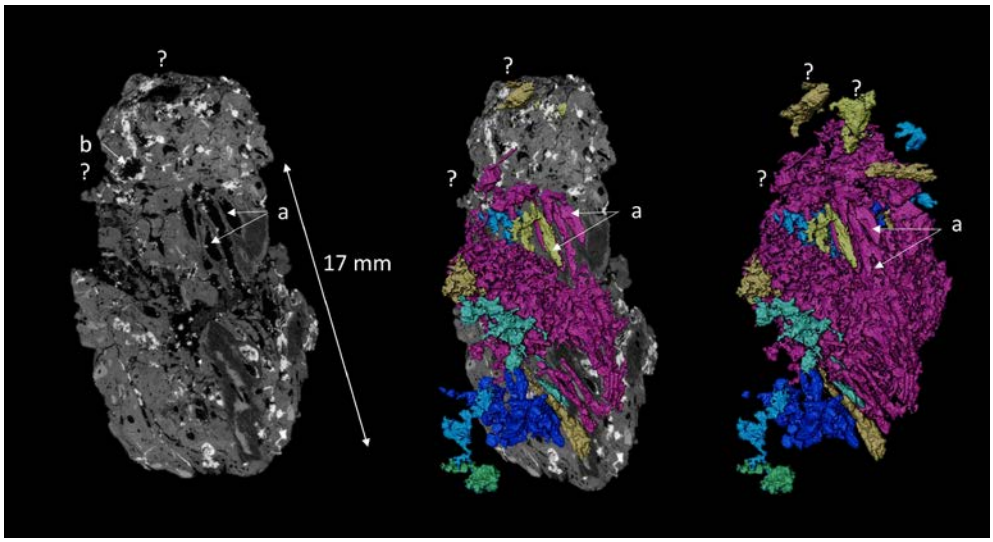


Figure VI.17 S4-4, scan 0.025 mm voxel. The large elongated pores in long cavernous bones (a) and the gypsum mineralisation which developed in cavities (b) render the detection of plant phantoms difficult.

VII List of herbaceous species used as reference material (Chapter 8)

Scientific name	Dutch name	English name	Family
Alliaria petiolata	Look-zonder-look	Garlic Mustard / Hedge Garlic	Brassicaceae
Althaea officinalis	Heemst	Marsh-mallow	Malvaceae
Arctium lappa	Grote klit	Greater Burdock	Asteraceae
Armoracia rusticana	Mierikswortel	Horse-radish	Brassicaceae
Aster tripolium	Zulte	Sea Aster	Asteraceae
Atriplex patula	Uitstaande melde	Common Orache/Spear-leaved Orache	Amaranthaceae
Atriplex portulacoides	Gewone zoutmelde	Sea Purslane	Amaranthaceae
Atriplex prostrata	Spiesmelde	Hastate Orache /Spear-leaved Orache	Chenopodiaceae
Barbarea vulgaris	Gewoon barbarakruid	Winter-cress / Yellow Rocket	Brassicaceae
Caltha palustris	Dotterbloem	Marsh Marigold	Ranunculaceae
Capsella bursa-pastoris	Herderstasje	Shepherd's-purse	Brassicaceae
Cardamine flexuosa	Bosveldkers	Wood Bitter-cress / Wavy Bitter-cr.	Brassicaceae
Cardamine hirsuta	Kleine veldkers	Hairy Bitter-cress	Brassicaceae
Cardamine pratensis	Pinksterbloem	Lady's Smock / Cuckooflower	Brassicaceae
Cerastium fontanum	Gewone hoornbloem	Common Mouse-ear	Caryophyllaceae
Chenopodium album	Melganzenvoet	Fat-hen	Amaranthaceae
Chenopodium polyspermum	Korrelganzenvoet	All-seed	Amaranthaceae
Chenopodium rubrum	Rode ganzenvoet	Red Goosefoot	Amaranthaceae
Cochlearia danica	Deens lepelblad	Early Scurvygrass	Brassicaceae
Cochlearia officinalis	Echt en Engels lepelblad	Common & Long-leaved Scurvygrass	Brassicaceae
Conium maculatum	Gevlekte scheerling	Hemlock	Apiaceae
Convolvulus sepium	Haagwinde	Hedge Bindweed	Convolvulaceae
Coronopus didymus	Kleine varkenskers	Lesser Swine-cress	Brassicaceae
Coronopus squamatus	Grove varkenskers	Swine-cress	Brassicaceae
Crambe maritima	Zeekool	Seakale	Brassicaceae
Erodium cicutarium	Reigersbek	Stork's-bill	Geraniaceae
Galium aparine	Kleefkruid	Cleavers	Rubiaceae
Hedera helix	Klimop	Ivy	Araliaceae
Lepidium campestre	Veldkruidkers	field cress or pepperwort	Brassicaceae
Lepidium draba	Pijlkruidkers	Hoary Cress	Brassicaceae
Limonium vulgare	Lamsoor	Common Sea-lavender	Plumbaginaceae
Lunaria annua	Tuinjudaspenning	Honesty	Brassicaceae
Malva sylvestris	Groot kaasjeskruid	Common Mallow	Malvaceae
Malva sylvestris	Groot kaasjeskruid	Common Mallow	Malvaceae
Nasturtium microphyllum	Slanke waterkers	One-rowed Water-cress	Brassicaceae
Nymphaea alba	Witte waterlelie	White Water-lily	Nymphaeaceae
Oxalis acetosella	Witte klaverzuring	Wood-sorrel	Oxalidaceae
Persicaria lapathifolia	Beklierde duizendknoop	Pale Persicaria	Polygonaceae
Phragmites australis	Riet	Common Reed	Poaceae
Plantago major	Grote en Getande weegbree	Greater Plantain	Plantaginaceae
Polygonum aviculare	Gewoon varkensgras	Knotgrass	Polygonaceae

Scientific name	Dutch name	English name	Family
Ranunculus acris	Scherpe boterbloem	Meadow Buttercup	Ranunculaceae
Ranunculus sceleratus	Blaartrekkende boterbloem	Celery-leaved Crowfoot	Ranunculaceae
Silene flos-cuculi	Echte koekoeksbloem	Ragged-Robin	Caryophyllaceae
Sisymbrium officinale	Gewone raket	Hedge Mustard	Brassicaceae
Sonchus asper	Gekroesde melkdistel	Prickly Sow-thistle	Asteraceae
Spergularia media	Gerande schijnspurrie	Greater Sea-spurrey	Caryophyllaceae
Stellaria media	Vogelmuur	Chickweed	Caryophyllaceae
Taraxacum officinale	Gewone paardebloem	Common Dandelion	Asteraceae
Triglochin maritima	Zoutgras	Arrow-grass	Juncaginaceae
Urtica dioica	Grote brandnetel	Stinging Nettle	Urticaceae
Viscum album	Maretak	Mistletoe	Santalaceae

VIII Pollen counts (Chapter 10)

sitenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
	N	N	N	N	N	N	N	N	N	N	N	N	N
SAP (total arboreal pollen)	138	.	7	11	73	53	1	53	5	1	126	47	3
SNAP (total non-arboreal pollen)	55	.	4	13	260	185	5	54	4	3	115	78	7
Trees (dry soils)	33	.	5	7	46	35	1	30	3	1	78	24	3
Trees (wet soils)	100	.	2	3	27	17	.	22	2	.	47	23	.
Forest herbs	5	.	.	1	1	1	.	1	.	.	1	.	.
Cultivated plants	.	.	.	.	4	.	.	.	.	.	14	.	.
Potential arable weeds and ruderals	1	.	.	1	1	.	.	4	.	.	1	1	.
Grassland plants	45	.	1	5	114	88	4	27	3	1	22	43	2
Other herbs	1	.	1	2	16	10	1	7	.	1	20	8	.
Tall-herb fen vegetation	2	.	.	.	10	2	.	.	.	1	14	4	.
Marsh and riparian vegetation	2	.	1	.	17	3	.	2	.	.	4	3	.
Aquatic plants	.	.	.	.	65	56	.	.	.	.	2	.	1
Heath and bog	1	.	.	1	2	.	.	3	.	.	2	2	.
Ferns	3	.	1	4	30	25	.	11	1	.	32	17	4
Plants of brackish and marine environments	.	.	.	.	.	1	.	.	.	.	4	.	.
Trees (dry soils)													
Betula (B)	+	.	1	.	5	1	.	3	.	.	7	.	.
Corylus (B)	11	.	3	6	14	6	.	14	1	.	34	10	2
Fraxinus excelsior-type (B)	.	.	.	.	.	1	.	.	.	.	.	.	.
Pinus (B)	3	.	1	1	4	6	.	5	2	1	7	1	1
Quercus (B)	11	.	.	.	11	8	1	7	.	.	11	9	.
cf. Quercus (B)	.	.	.	.	.	.	.	.	.	.	5	.	.
Rhamnus cathartica	1	.	.	.	.	.	.	.	.	.	.	.	.
Sorbus-groep (B)	.	.	.	.	.	.	.	.	.	.	1	.	.
Tilia (B)	4	.	.	.	1	.	.	.	.	.	3	.	.
Ulmus (B)	2	.	.	.	11	13	.	1	.	.	10	4	.
Viburnum opulus-type (B)	1	.	.	.	.	.	.	.	.	.	.	.	.
Trees (wet soils)													
Alnus (B)	100	.	2	3	26	17	.	21	2	.	47	22	.
Salix (B)	+	.	.	.	1	.	.	1	.	.	.	1	.
Forest herbs													
Hedera helix (B)	.	.	.	.	.	.	.	1	.	.	.	.	.
Humulus lupulus (P)	5	.	.	1	1	.	.	.	.	.	1	.	.

sitenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Lonicera periclymenum-type (B)	.	.	.	.	.	1	.	.	.	.	.	.	.
Cultivated plants					.	.							
Cerealia-type	.	.	.	.	4	.	.	.	.	.	9	.	.
cf. Cerealia-type	.	.	.	.	.	.	.	.	.	.	5	.	.
Potential arable weeds and ruderals													
Artemisia (B)	1	.	.	1	.	.	.	4	.	.	1	1	.
Polygonum aviculare-type (B)	.	.	.	.	1	.	.	.	.	.	.	.	.
Grassland plants													
Fabaceae p.p. (B)	.	.	.	.	1	.	.	.	.	.	.	.	.
Plantago	.	.	.	.	1	1	.	.	.	.	.	.	.
Poaceae (B)	44	.	1	5	108	85	4	27	3	1	20	42	.
Poaceae >37 mu	.	.	.	.	4	2	.	.	.	.	.	1	2
Rubiaceae (B)	.	.	.	.	.	.	.	.	.	.	2	.	.
Rumex acetosa-type (P)	1	.	.	.	.	.	.	.	.	.	.	.	.
Other herbs													
Apiaceae (B)	.	.	.	.	.	.	.	.	.	.	.	1	.
Asteraceae liguliflorae	.	.	.	2	4	1	.	1	.	.	.	5	.
Asteraceae tubuliflorae	.	.	.	.	.	.	.	.	.	.	2	.	.
Ballota-type (B)	.	.	.	.	.	1	.	.	.	.	2	1	.
Brassicaceae (B)	.	.	.	.	.	.	.	.	.	.	.	.	.
cf. Anagallis-type (B)	.	.	.	.	.	1	.	.	.	.	1	.	.
Chenopodiaceae p.p. (B)	1	.	1	.	8	5	.	6	.	1	5	1	.
Lathyrus-type (B)	.	.	.	.	1	2	.	.	.	.	.	.	.
Matricaria-type (B)	.	.	.	.	.	.	.	.	.	.	.	.	.
Rosaceae	.	.	.	.	.	.	.	.	.	.	7	.	.
Rosaceae cf. Rubus	.	.	.	.	3	.	.	.	.	.	3	.	.
Tall-herb fen vegetation										.			
Filipendula (B)	2	.	.	.	.	1	.	.	.	.	6	.	.
Filipendula cf. vulgaris (B)	.	.	.	.	5	.	.	.	.	1	2	3	.
Mentha-type (B)	.	.	.	.	+	.	.	.	.	.	1	.	.
Solanum dulcamara (B)	.	.	.	.	5	1	.	.	.	.	5	1	.
Marsh and riparian vegetation													
Alisma-type (B)	.	.	.	.	.	.	.	.	.	.	1	.	.
Cyperaceae (B)	2	.	.	.	13	2	.	1	.	.	1	2	.
Sparganium erectum-type (P)	.	.	.	.	2	.	.	.	.	.	.	.	.

sitenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Typha angustifolia	.	.	1	.	2	1	.	1	.	.	.	1	.
Typha latifolia-type (B)	.	.	.	.	.		.	.	.	.	2	.	.
Aquatic plants													
Lemnaceae (B)	.	.	.	.	1	.	.	.	.	.	.	.	
Nymphaea (B)	.	.	.	.	64	56	.	.	.	.	2	.	1
Microfossils (fresh water)													
cf. Debarya (v)	.	.	1	.	.	.	.	.	.	.	.	.	.
Pediastrum (dotted)	1	.	.	.	.	.	.	2	.	.	1	.	.
Pediastrum	.	.	.	.	7	.	.	.	.	.	.	.	.
Type 128A	.	.	.	.	1	.	.	.	.	.	.	.	.
Heath and bog plants													
Calluna vulgaris (B)	1	.	.	.	1	.	.	.	.	.	1	1	.
Ericaceae	.	.	.	.	.	.	.	1	.	.	.	.	.
Corylus/Myrica gale (B)	.	.	.	.	.	.	.	1	.	.	.	.	.
Sphagnum	.	.	.	1	1	.	.	1	.	.	1	1	.
Ferns													
Dryopteris-type	3	.	.	3	30	25	.	11	1	.	31	16	4
Osmunda regalis	.	.	.	.	.	+	.	.	.	.	.	.	.
Polypodium	+	.	1	1	.	.	.	.	.	.	1	1	.
Plants of brackish and marine environments													
Althaea officinalis (P)	.	.	.	.	.	1	.	.	.	.	4	.	.
Microfossils of brackish and marine environments													
Dinoflagellate cyst	.	.	.	.	1	.	.	1	.	.	1	.	.
Helminths													
Helminth, egg	.	.	.	.	1	.	.	.	.	.	.	.	.
Trichuris, egg	.	.	.	.	.	.	.	.	.	.	6	.	.
Dung fungi													
Cercophora-type (T.112)	.	.	.	.	3	.	.	.	.	.	.	.	.
Chaetomium (T.7A)	10	.	.	.	+	.	.	.	.	.	.	.	.
Sordaria-type (T.55A)	.	.	.	.	5	.	.	.	.	.	.	.	.
Microfossils animal origin													
Ovis, hair, fine wool	.	.	.	.	.	.	.	2	.	.	.	.	.
Barbule, feather Passeriformes/ Charadriiformes singing birds/waders	.	.	.	.	+	.	.	.	.	.	.	.	.
cf. Barbule feather, charred	.	.	.	.	+	.	.	.	.	.	.	.	.

sitenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Chitinous remains, animal origin	.	.	.	.	+	+	.	.	.	.	.	.	.
Other microscopic plant remains												.	.
Rosette-shape cells plant tissue (cf. Malus or Nymphaea)	+	.	.	+	+	+	.	.	.	+	+	+	.
Nymphaea alba, seed testa fragment	+	.	.	.	++++	+++	.	.	.	.	.	.	.
cf. Nymphaea alba, seed testa fragment (v?)	.	.	.	.			.	.	.	.	.	+	.
Nymphaea alba, suberized basal cell T.127	.	.	.	.	+	+	.	.	.	.	.	.	.
trichosclereid, transparant, cf. Nymphaea alba	.	.	.	.			.	.	.		1	.	.
Darkyellow organic material	++	+	+++	.	++++	+++	+++	+++	+	++	+++	+++	+++
Plant tissue, Large cells thick spotted cell walls	.	.	.	.	+	+	.	.	.	.	.	.	.
Epidermis, rectangular cells, cf. Allium	+	.	.	.	.	+	.	.	.	.	.	.	.
Plant tissue, transparant thick cellwalls	.	.	.	+	.	.	+	.	+	+	+	.	+
Uncharred epidermis Poaceae/Cyperaceae	.	.	.	.	.	.	.	.	.	.	.	+	+
Scalariform perforation plate (HdV-114)	.	.	.	.	+	.	.	4	.	.	1	.	.
Woody rings, plant vessels, charred	5	.	+	.	.	+	+	.	.	+	1	.	+
Charred woody vessel, possibly Alnus	.	+	.	.	.	+	+	+	.	.	.	.	+
Charred cf. coniferous wood	.	.	.	.	++	+	+	.	+	.	+	+	.
Charcoal, fragments	+	++++	++	+	.	++	+	++	++	++	+	+	+
Charred plant remains	++++	++++	++++	++	.	+++	++++	+++	++++	++++	+++	+	++++
Charred epidermis cf Phragmites	.	.	.	+	.	+	+	+	.	.	.	+	+
Cerealia, pericarp (likely Triticum cf. dicoccum)	.	.	.	.	.	.	.	.	.	+	.	.	.
Cerealia, pericarp (likely Hordeum)	.	.	.	.	+	.	.	.	.	.	.	.	.
Charred epidermis cf Cerealia	.	+	.	.	.	.	+	.	.	.	.	.	.
Triticum cf. dicoccum, charred epidermis	.	.	+	.	.	+	.	.	+	.	+	+	.
Charred epidermis Poaceae/Cyperaceae	+	+++	+	+	+++	++	++	+++	++	++	+	+	+

sitenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Charred epidermis Poaceae/Cyperaceae with stomata	+	++	+	.	.	++	+	+++	+++	++	+	+	+
Charred epidermis, Cyperaceae	.	++	+	.	.	.	+	++	+	+	.	.	+
Phytolith	.	.	1	.	.	.	+	.	.	+	.	.	+
Phytolith/sponge spicule	.	.	.	.	.	.	.	.	.	.	+	1	+
Other fungal spores							.	.	.	.	.	.	.
Gelasinospora cf. G. reticulispora (T.2)	1	.	.	.	.	.	.	.	.	.	.	.	1
Reticulate Ustilospore (cf. HdV-256)	.	.	.	.	+	.	.	.	.	.	.	.	.
cf. Uromyces, fungal spore	12	.	+	.	1	+	+	1	.	+	+	4	+
cf. Basidiomyceta, fungal spore	5	.	+	.	.	+	.	.	.	.	10	21	+
cf. Puccinia, fungal spore	+	.	.	.	.	+	.	.	.	.	.	.	.
Unknown fungal spores	.	.	++	.	.	.	.	.	.	.	.	.	+
Glomus	1	.	.	.	.	.	.	.	.	.	.	.	.
Indet pollen	1	.	.	.	2	1	.	1	.	.	4	4	.
Concentration calculation													
Pollen concentration (n/ml)	very low	extremely low	extremely low	extremely low	8.906	very low	extremely low	6.433	extremely low	extremely low	very low	very low	extremely low
Lycopodium spores per tablet	17461	18583	17461	17461	18583	18583	17461	18583	18583	18583	17461	17461	18583
Number of tablets	1	1	1	1	1	1	1	1	1	1	1	1	1
Lycopodium spores counted	+++	+++	++	++++	233	+++	+	104	++++	+++	++	++++	++++
Total pollensum	193	0	11	24	333	238	6	107	9	4	241	125	10
Sample volume in ml	3	3	3	0,5	3	3	3	3	0,8	3	3	3	0,3
number of slides counted (+ scanned)	3+2	2	5	5	7	7	5	8	7	2	4+1	5	2

Legend: c = charred, cf.= possible, B= pollentype according to Beug; P= pollentype according to Punt , += present, ++= numerous, +++= abundant, ++++= extremely abundant.

IX Pollen percentages (Chapter 10)

Samplenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
Findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
Labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
	%	%	%	%	%	%	%	%	%	%	%	%	%
SAP (total arboreal pollen)	71,5	.	63,6	45,8	22,2	22,3	16,7	49,5	55,6	25,0	52,3	37,6	30,0
SNAP (total non-arboreal pollen)	28,5	.	36,4	54,2	77,8	77,7	83,3	50,5	44,4	75,0	47,7	62,4	70,0
Trees (dry soils)	17,1	.	45,5	29,2	13,8	14,7	16,7	28,0	33,3	25,0	32,4	19,2	30,0
Trees (wet soils)	51,8	.	18,2	12,5	8,1	7,1	.	20,6	22,2	.	19,5	18,4	.
Forest herbs	2,6	.	.	4,2	0,3	0,4	.	0,9	.	.	0,4	.	.
Cultivated plants	.	.	.	.	1,2	.	.	.	.	.	5,8	.	.
Potential arable weeds and ruderals	0,5	.	.	4,2	0,3	.	.	3,7	.	.	0,4	0,8	.
Grassland plants	23,3	.	9,1	20,8	34,2	37,0	66,7	25,2	33,3	25,0	9,1	34,4	20,0
Other herbs	0,5	.	9,1	8,3	4,8	4,2	16,7	6,5	.	25,0	8,3	6,4	.
Tall-herb fen vegetation	1,0	.	.	.	3,0	0,8	.	.	.	25,0	5,8	3,2	.
Marsh and riparian vegetation	1,0	.	9,1	.	5,1	1,3	.	1,9	.	.	1,7	2,4	.
Aquatic plants	.	.	.	.	19,5	23,5	.	.	.	.	0,8	.	10,0
Heath and bog	0,5	.	.	4,2	0,6	.	.	2,8	.	.	0,8	1,6	.
Ferns	1,6	.	9,1	16,7	9,0	10,5	.	10,3	11,1	.	13,3	13,6	40,0
Plants of brackish and marine environments	.	.	.	.	.	0,4	.	.	.	.	1,7	.	.
Trees (dry soils)													
Betula (B)	+	.	9,1	.	1,5	0,4	.	2,8	.	.	2,9	.	.
Corylus (B)	5,7	.	27,3	25,0	4,2	2,5	.	13,1	11,1	.	14,1	8,0	20,0
Fraxinus excelsior-type (B)	.	.	.	.	.	0,4	.	.	.	.	.	.	.
Pinus (B)	1,6	.	9,1	4,2	1,2	2,5	.	4,7	22,2	25,0	2,9	0,8	10,0
Quercus (B)	5,7	.	.	.	3,3	3,4	16,7	6,5	.	.	4,6	7,2	.
cf. Quercus (B)	.	.	.	.	.	.	.	.	.	.	2,1	.	.
Rhamnus cathartica	0,5	.	.	.	.	.	.	.	.	.	.	.	.
Sorbus-groep (B)	.	.	.	.	.	.	.	.	.	.	0,4	.	.
Tilia (B)	2,1	.	.	.	0,3	.	.	.	.	.	1,2	.	.
Ulmus (B)	1,0	.	.	.	3,3	5,5	.	0,9	.	.	4,1	3,2	.
Viburnum opulus-type (B)	0,5	.	.	.	.	.	.	.	.	.	.	.	.
Trees (wet soils)													
Alnus (B)	51,8	.	18,2	12,5	7,8	7,1	.	19,6	22,2	.	19,5	17,6	.
Salix (B)	+	.	.	.	0,3	.	.	0,9	.	.	.	0,8	.
Forest herbs													
Hedera helix (B)	.	.	.	.	.	.	.	0,9	.	.	.	.	.
Humulus lupulus (P)	2,6	.	.	4,2	0,3	.	.	.	.	.	0,4	.	.

Samplenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
Findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
Labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Lonicera periclymenum-type (B)	.	.	.	.	.	0,4	.	.	.	.	.	.	.
Cultivated plants													
Cerealia-type	.	.	.	.	1,2	.	.	.	.	.	3,7	.	.
cf. Cerealia-type	.	.	.	.	.	.	.	.	.	.	2,1	.	.
Potential arable weeds and ruderals													
Artemisia (B)	0,5	.	.	4,2	.	.	.	3,7	.	.	0,4	0,8	.
Polygonum aviculare-type (B)	.	.	.	.	0,3	.	.	.	.	.	.	.	.
Grassland plants													
Fabaceae p.p. (B)	.	.	.	.	0,3	.	.	.	.	.	.	.	.
Plantago	.	.	.	.	0,3	0,4	.	.	.	.	.	.	.
Poaceae (B)	22,8	.	9,1	20,8	32,4	35,7	66,7	25,2	33,3	25,0	8,3	33,6	.
Poaceae >37 mu	.	.	.	.	1,2	0,8	.	.	.	.	.	0,8	20,0
Rubiaceae (B)	.	.	.	.	.	.	.	.	.	.	0,8	.	.
Rumex acetosa-type (P)	0,5	.	.	.	.	.	.	.	.	.	.	.	.
Other herbs													
Apiaceae (B)	.	.	.	8,3	1,2	0,4	.	0,9	.	.	.	4,0	.
Asteraceae liguliflorae	.	.	.	.	.	.	.	.	.	.	0,8	.	.
Asteraceae tubuliflorae	.	.	.	.	.	0,4	.	.	.	.	0,8	0,8	.
Ballota-type (B)	.	.	.	.	.	.	.	.	.	.	.	.	.
Brassicaceae (B)	.	.	.	.	.	0,4	.	.	.	.	0,4	.	.
cf. Anagallis-type (B)	.	.	.	.	.	.	.	.	.	.	.	0,8	.
Chenopodiaceae p.p. (B)	0,5	.	9,1	.	2,4	2,1	.	5,6	.	25,0	2,1	0,8	.
Lathyrus-type (B)	.	.	.	.	0,3	0,8	.	.	.	.	.	.	.
Matricaria-type (B)	.	.	.	.	.	.	16,7	.	.	.	.	.	.
Rosaceae	.	.	.	.	.	.	.	.	.	.	2,9	.	.
Rosaceae cf. Rubus	.	.	.	.	0,9	.	.	.	.	.	1,2	.	.
Tall-herb fen vegetation													
Filipendula (B)	1,0	.	.	.	.	0,4	.	.	.	.	2,5	.	.
Filipendula cf. vulgaris (B)	.	.	.	.	1,5	.	.	.	.	25,0	0,8	2,4	.
Mentha-type (B)	.	.	.	.	+	.	.	.	.	.	0,4	.	.
Solanum dulcamara (B)	.	.	.	.	1,5	0,4	.	.	.	.	2,1	0,8	.
Marsh and riparian vegetation													
Alisma-type (B)	.	.	.	.	.	.	.	.	.	.	0,4	.	.
Cyperaceae (B)	1,0	.	.	.	3,9	0,8	.	0,9	.	.	0,4	1,6	.

Samplenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
Findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
Labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Sparganium erectum-type (P)	.	.	.	.	0,6	.	.	.	.	.	.	.	.
Typha angustifolia	.	.	9,1	.	0,6	0,4	.	0,9	.	.	.	0,8	.
Typha latifolia-type (B)	.	.	.	.	.	.	.	.	.	.	0,8	.	.
Aquatic plants													
Lemnaceae (B)	.	.	.	.	0,3	.	.	.	.	.	.	.	.
Nymphaea (B)	.	.	.	.	19,2	23,5	.	.	.	.	0,8	.	10,0
Microfossils (fresh water)													
cf. Debarya (v)	.	.	9,1	.	.	.	.	.	.	.	.	.	.
Pediastrum (dotted)	0,5	.	.	.	.	.	.	1,9	.	.	0,4	.	.
Pediastrum	.	.	.	.	2,1	.	.	.	.	.	.	.	.
Type 128A	.	.	.	.	0,3	.	.	.	.	.	.	.	.
Heath and bog plants													
Calluna vulgaris (B)	0,5	.	.	.	0,3	.	.	.	.	.	0,4	0,8	.
Ericaceae	.	.	.	.	.	.	.	0,9	.	.	.	.	.
Corylus/Myrica gale (B)	.	.	.	.	.	.	.	0,9	.	.	.	.	.
Sphagnum	.	.	.	4,2	0,3	.	.	0,9	.	.	0,4	0,8	.
Ferns													
Dryopteris-type	1,6	.	.	12,5	9,0	10,5	.	10,3	11,1	.	12,9	12,8	40,0
Osmunda regalis	.	.	.	.	.	+	.	.	.	.	.	.	.
Polypodium	+	.	9,1	4,2	.	.	.	.	.	.	0,4	0,8	.
Plants of brackish and marine environments													
Althaea officinalis (P)	.	.	.	.	.	0,4	.	.	.	.	1,7	.	.
Microfossils of brackish and marine environments													
Dinoflagellate cyst	.	.	.	.	0,3	.	.	0,9	.	.	0,4	.	.
Helminths													
Helminth, egg	.	.	.	.	0,3	.	.	.	.	.	.	.	.
Trichuris, egg	.	.	.	.	.	.	.	.	.	.	2,5	.	.
Dung fungi													
Cercophora-type (T.112)	.	.	.	.	0,9	.	.	.	.	.	.	.	.
Chaetomium (T.7A)	5,2	.	.	.	+	.	.	.	.	.	.	.	.
Sordaria-type (T.55A)	.	.	.	.	1,5	.	.	.	.	.	.	.	.
Microfossils animal origin													
Ovis, hair, fine wool	.	.	.	.	.	.	.	1,9	.	.	.	.	.
Barbule, feather Passeriformes/ Charadriiformes singing birds/waders	.	.	.	.	+	.	.	.	.	.	.	.	.

Samplenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
Findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
Labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
cf. Barbule feather, charred	.	.	.	.	+	.	.	.	.	.	.	.	.
Chitinous remains, animal origin	.	.	.	.	+	+	.	.	.	.	.	.	.
Other microscopic plant remains													
Rosette-shape cells plant tissue (cf. Malus or Nymphaea)	+	.	.	+	+	+	.	.	.	+	+	+	.
Nymphaea alba, seed testa fragment	+	.	.	.	++++	+++	.	.	.	.	.	.	.
cf. Nymphaea alba, seed testa fragment (c?)	.	.	.	.	.	.	.	.	.	.	.	+	.
Nymphaea alba, suberized basal cell T.127	.	.	.	.	+	+	.	.	.	.	.	.	.
trichosclereid, transparant, cf. Nymphaea alba	.	.	.	.	.	.	.	.	.	.	+	.	.
Darkyellow organic material	++	+	+++	.	++++	+++	+++	+++	+	++	+++	+++	+++
Plant tissue, large cells, spotted walls	.	.	.	.	+	+	.	.	.	.	.	.	.
Plant tissue, cells rectangular	+	.	.	.	.	+	.	.	.	.	.	.	.
Plant tissue, transparant thick cellwalls	.	.	.	+	.	.	+	.	+	+	+	.	+
epidermis Poaceae/ Cyperaceae	.	.	.	.	.	.	.	.	.	.	.	+	+
Scalariform perforation plate (HdV-114)	.	.	.	.	+	.	.	++	.	.	+	.	.
Woody rings, plant vessels, charred	+	.	+	.	.	+	+	.	.	+	+	.	+
Charred woody vessel, possibly Alnus	.	+	.	.	.	+	+	+	.	.	.	.	+
Charred cf coniferous wood	.	.	.	.	++	+	+	.	+	.	+	+	.
Charcoal, fragments	+	++++	++	+	.	++	+	++	++	++	+	+	+
Charred plant remains	++++	++++	++++	++	.	+++	++++	+++	++++	++++	+++	+	++++
Charred epidermis cf Phragmites	.	.	.	+	.	+	+	+	.	.	.	+	+
Cerealia, pericarp (likely Triticum cf. dicoccum)	.	.	.	.	.	.	.	.	.	+	.	.	.
Cerealia, pericarp (likely Hordeum)	.	.	.	.	+	.	.	.	.	.	.	.	.
Charred epidermis cf Cerealia	.	+	.	.	.	.	+	.	.	.	.	.	.
Triticum cf. dicoccum, charred epidermis	.	.	+	.	.	+	.	.	+	.	+	+	.

Samplenumber	Hardinxveld	S3-2	S3-4	S3-5	S3-10	S3-11	S3-13	S3-15	S3-18	S3-20	S3-28	S4-1	S4-4
Findnumber	19952	54516	54655	51179	54845	54827	53847	43716	54752	57443	54488	1420	629
Labcode	BX9300	BX9099	BX9295	BX9296	BX9100	BX9101	BX9297	BX9102	BX9103	BX9104	BX9298	BX9299	BX9105
Charred epidermis Poaceae/Cyperaceae	+	+++	+	+	+++	++	++	+++	++	++	+	+	+
Charred epidermis Poaceae/Cyperaceae with stomata	+	++	+	.	.	++	+	+++	+++	++	+	+	+
Charred epidermis, Cyperaceae	.	++	+	.	.	.	+	++	+	+	.	.	+
Phytolith	.	.	+	.	.	.	+	.	.	+	.	.	+
Phytolith/sponge spicule	.	.	.	.	.	.	.	.	.	.	+	+	+
Other fungal spores					.	.	.	.	.	.	.	.	.
Gelasinospora cf. G. reticulispora (T.2)	+	.	.	.	.	.	.	.	.	.	.	.	1
Reticulate Ustilospore (cf. HdV-256)	.	.	.	.	+	.	.	.	.	.	.	.	.
cf. Uromyces, fungal spore	++	.	+	.	+	+	+	+	.	+	+	+	+
cf. Basidiomyceta, fungal spore	+	.	+	.	.	+	.	.	.	.	++	++	+
cf. Puccinia, fungal spore	+	.	.	.	.	+	.	.	.	.	.	.	.
Unknown fungal spores	.	.	++	.	.	.	.	.	.	.	.	.	+
Glomus	+	.	.	.	.	.	.	.	.	.	.	.	.
Indet pollen	0,5	.	.	.	0,6	0,4	.	0,9	.	.	1,7	3,2	.
Concentration calculation													
Pollen concentration (n/ml)	very low	extremely low	extremely low	extremely low	8.906	very low	extremely low	6.433	extremely low	extremely low	very low	very low	extremely low
Lycopodium spores per tablet	17461	18583	17461	17461	18583	18583	17461	18583	18583	18583	17461	17461	18583
Number of tablets	1	1	1	1	1	1	1	1	1	1	1	1	1
Lycopodium spores counted	+++	+++	++	++++	233	+++	+	104	++++	+++	++	++++	++++
Total pollensum	193	0	11	24	333	238	6	107	9	4	241	125	10
Sample volume in ml	3	3	3	0,5	3	3	3	3	0,8	3	3	3	0,3
number of slides counted (+ scanned)	3+2	2	5	5	7	7	5	8	7	2	4+1	5	2

Legend: c = charred, cf.= possible, B= pollentype according to Beug; P= pollentype according to Punt , += present, ++= numerous, +++= abundant, ++++= extremely abundant.

X Pollen, spores and microfossils in intestinal parasite slides (Chapter 10)

site	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
sample-nr.	19952	54655	54845	54827	53847	54488	1420	629
labcode	BXD9300	BXD9295	BXD9100	BXD9101	BXD9297	BXD9298	BXD9299	BXD9105
Sums:	N	N	N	N	N	N	N	N
Pollen trees	.	.	14	3	1	3	1	1
Pollen cultivated species	.	1	.	.	.	.	2	.
Pollen herbs	1	.	6	5	1	.	5	.
Fern and moss spores	1	.	7	3	.	6	1	1
Pollen plants of brackish and marine environments	.	.	.	.	.	2	.	1
Pollen aquatics	.	.	28	38	.	2	.	.
Counts:								
Pollen trees								
Alnus	.	.	1	.	.	1	.	.
Betula	.	.	1	.	.	.	.	.
Pinus	.	.	12	3	1	1	1	1
Tilia	.	.	.	.	.	1	.	.
Pollen cultivated plants								
Cerealia-type	.	1	.	.	.	.	2	.
Pollen herbs								
Apiaceae	.	.	1	.	.	.	.	.
Asteraceae, liguliflorae	.	.	.	.	.	.	1	.
Asteraceae, tubuliflorae	.	.	.	.	.	.	1	.
Caryophyllaceae	1	.	.	.	.	.	.	.
Chenopodiaceae	.	.	.	1	.	.	.	.
Ericaceae	.	.	.	.	.	.	2	.
Fabaceae	.	.	.	1	.	.	.	.
Poaceae	.	.	5	3	1	.	1	.
Fern and moss spores								
Dryopteris-type (M)	1	.	7	3	.	4	1	.
Polypodium (M)	.	.	.	.	.	1	.	1
Sphagnum (M)	.	.	.	.	.	1	.	.
Pollen plants of brackish and marine environments								
Althaea officinalis	.	.	.	.	.	2	.	.
Armeria/Limonium	.	.	.	.	.	.	.	1
Aquatics								
Nymphaea (B)	.	.	28	38	.	1	.	.
Typha latifolia	.	.	.	.	.	1	.	.
Microfossils (fresh water)								
Epithemia cf. adnata	.	.	1	.	.	.	.	.
Spongillidae spicules (T.220/T.424)	.	.	+	1	.	.	+	.
Microfossils (brackish/salt)								
cf. Actinocyclus	.	.	+	5	+	+	+	1
Actinoptychus senarius	.	+	+	4	+	+	+	1

site	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
sample-nr.	19952	54655	54845	54827	53847	54488	1420	629
labcode	BXD9300	BXD9295	BXD9100	BXD9101	BXD9297	BXD9298	BXD9299	BXD9105
Aulacodiscus argus	.	+	+	4		+	+	1
Foraminifera	30	.	.	.	.	.	.	.
Podosira stelliger (T.5085)	.	+	.	.	.	+	.	.
Fungal spores								
Cercophora-type (T.112)	1	.	.	.	.	.	.	.
Chaetomium (T.7A)	.	.	.	.	.	+	.	.
Small lightbrown fungal spores (cf. Uromyces)	.	.	.	.	.	+	.	.
Small darkbrown fungal spores (cf. Uromyces)	.	.	.	.	.	+	.	.
Type 256, reticulate ustilospore	.	.	.	.	.	++	.	.
Type 183	.	.	+	.	.	.	.	.
Urocystis	.	.	+	.	.	.	.	.
Glomus	+	.	+	.	.	.	.	.
Animal (?) remains								
Hair, cf. fine wool sheep	.	.	.	.	1	.	.	.
Hair, curled, cf. fine wool sheep	1	.	.	.	.	.	.	.
Hair, likely red deer	.	.	.	1	.	.	.	.
Hooklet, chitineus, long	.	.	1	3	.	.	.	.
Hooklets, chitineus small (T.180?)	.	.	10	7	.	+	.	.
Animal remains, small hooklets/hairs	.	.	.	.	.	.	.	1
Testate amoebae, round	+	.	.	.	.	29	.	.
Organism 220-179 um	1	.	.	.	.	.	.	.
Other botanical remains (edible)								
cf. Apple, epidermis (uncharred)	.	.	.	+	.	.	.	.
Cerealia, bran	.	.	+	.	.	.	.	.
Nymphaea, seed testa fragments	.	.	+++	+++	.	+	.	.
Other botanical remains								
Sphagnum, leaf fragments	.	.	.	.	.	+	+	.
Thick walled plant cel tissue	.	.	.	.	+	+	+	.
Uncharred plant remains	++++	.	++	+++	+	++++	+++	+
Charcoal fragments, coniferous wood	+	.	.	.	+	+	.	.
Charcoal, indet, fragments	+	++++	++	++	++	+	+	+++
Charred plant tissue, (round cells)	.	.	.	+	.	+	.	.
Charred plant material, cf. graminoid	+	.	+	+	.	.	.	+
Plant/wood remains, vessel rings, charred	.	+	.	+	.	.	+	.

site	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
sample-nr.	**19952**	**54655**	**54845**	**54827**	**53847**	**54488**	**1420**	**629**
labcode	**BXD9300**	**BXD9295**	**BXD9100**	**BXD9101**	**BXD9297**	**BXD9298**	**BXD9299**	**BXD9105**
Plant remains, indet, charred	+	+++	++	++	++	++	+	+++
Epidermis Phragmites, charred	.	.	+	+	.	+	+	+
Epidermis, graminoid, charred	+	+	++	++	+	+	+	.
Epidermis, charred	+	+	++	++	+	+	+	+++
Phytoliths (charred?)	+	+	++	++	++	+	+	+
Phytoliths (transparent)	+	+	+++	++	++	+	+	+
gegevens t.b.v. concentratieberekening								
Exoten per pil	18407	18407	18407	18407	18407	18407	18407	18407
Aantal pillen met exoot	1	1	1	1	1	1	1	1
Getelde exoten	189	437	287	356	452	185	676	1465
Total amount pollen	2	1	55	49	2	13	9	3
concentration pollen (n/ml)	97	14	705	845	27	259	82	19
Monstervolume in ml	2	3	5	3	3	5	3	2

Legend: c = charred, cf.= possible, B= pollentype accoring to Beug; P= pollentype accoring to Punt , += present, ++= numerous, +++= abundant, ++++= extremely abundant.

XI Trichuris eggs measurements (Chapter 11)

Sample	Find	labcode	length (um)	width (um)	n (measured)	n total (<58)
Hardinxveld	19952	BXD9300	-	-	-	-
S3-10	54845	BXD9100	49,8	26,1	11	11
S3-11	54827	BXD9101	51,4	25,8	8	8
S3-13	53814	BXD9297	56,4	24,5	2	2
S3-28	54488	BXD9298	52,1	26,1	25	183
S4-1	1420	BXD9299	48,1	27,4	4	4
S4-4	629	BXD9105	50,4	26,5	28	43

XII Intestinal parasites counts (Chapter 11)

Samplenumber	Hardinxveld	S3-4	S3-10	S3-11	S3-13	S3-28	S4-1	S4-4
Findnumber	**19952**	**54655**	**54845**	**54827**	**53814**	**54488**	**1420**	**629**
Labcode	**BXD9300**	**BXD9295**	**BXD9100**	**BXD9101**	**BXD9297**	**BXD9298**	**BXD9299**	**BXD9105**
Sums:	N	N	N	N	N	N	N	N
Sum eggs intestinal parasites (helminths)	2	1	86	81	2	195	6	45
Intestinal nematodes (roundworms)	.	1	11	7	2	84	5	44
Intestinal cestodes (tapeworm)	.	.	75	73	.	5	.	.
Liver and lung trematodes (flukes)	2	.	.	1	.	6	1	1
Counts:								
Intestinal nematodes (roundworms)								
Capillaria sp., egg	.	1	.	.	.	.	.	.
Dioctophyma sp., egg	.	.	.	.	.	.	1	1
Trichuris trichiura/suis (<59x28 µm)	.	.	11	7	2	184	4	43
Intestinal cestodes	.	.	.					
Diphyllobothrium sp., egg		.	8	8	.	.	.	.
Diphyllobothriidae(/trematoda), egg (54-66 µm)	.	.	67	65	.	5	.	.
Liver and lung trematodes (flukes)	.	.	.					
Opisthorchiidae, egg	.	.	.	1	.	6	1	1
Trematoda, indet., egg (> 86 µm)	2	.	.	.	.	.	.	.
Other Nematoda	.	.	.					
Free-living nematode, egg with larva	.	.	.	.	.	.	6	.
Free-living nematode, worm	.	.	.	.	.	.	1	.
Concentration calculation								
Concentration helminth eggs (n/ml)	97	14	1103	1396	27	3880	54	283
Lycopodium spores per tablet	18407	18407	18407	18407	18407	18407	18407	18407
N tablets Lycopodium spores	1	1	1	1	1	1	1	1
Number of Lycopodium counts	189	437	287	356	452	185	676	1465
Total amount helminth eggs	2	1	86	81	2	195	6	45
Monstervolume in ml	2	3	5	3	3	5	3	2

XIII Species list of all observed taxa (plants and animals) in Swifterbant coprolites (Chapter 13)

English	Nederlands	Scientific (Latin)
Plants		
Alder	Els	Alnus sp.
Amaranth/ Goosefoot family	Ganzenvoetfamilie	Chenopodiaceae
Ash	Es	Fraxinus excelsior
Barley	Gerst	Hordeum sp.
Birch	Berk	Betula sp.
Bittersweet	Bitterzoet	Solanum dulcamara
Bog-myrtle	Wilde gagel	Myrica gale
Bramble/ Raspberry	Braam/ Framboos	Rubus sp.
Branched bur-reed	Grote en Blonde egelskop	Sparganium erectum
Buckler/ Male fern	Niervaren	Dryopteris-type
Buckthorn	Wegedoorn	Rhamnus cathartica
Bulrush	Grote lisdodde	Typha latifolia
Carrot family	Schermbloemenfamilie	Apiaceae
Cereals	Granen	Cerealia
Chamomile	Kamille	Matricaria-type
Common Sorrel	Veldzuring	Rumex acetosa
Composite family ray florets	Composietenfamilie lintbloemig	Asteraceae liguliflorae
Composite family disc florets	Composietenfamilie buisbloemig	Asteraceae tubuliflorae
Crab (wild) apple	Wilde appel	Malus sylvestris
Dropwort	Knolspirea	Filipendula vulgaris
Duckweed family	Eendenkroosfamilie	Lemnaceae
Elder	Gewone vlier	Sambucus nigra
Elm	Iep	Ulmus sp.
Emmer wheat	Emmer tarwe	Triticum dicoccum
Everlasting-pea/ Vetchling	Lathyrus	Lathyrus-type
Grass family	Grassenfamilie	Poaceae
Guelder-rose	Gelderse roos	Viburnum opulus-type
Hawthorn	Eenstijlige meidoorn	Crataegus monogyna
Hazel	Hazelaar	Corylus avellana
Heather	Struikhei	Calluna vulgaris
Heather family	Heifamilie	Ericaceae
Holly	Hulst	Ilex aquifolium
Honeysuckle	Wilde kamperfoelie-type	Lonicera periclymenum
Hop	Hop	Humulus lupulus
Horehound	Ballote	Ballota-type
Ivy	Klimop	Hedera helix
Knotgrass	Gewoon varkensgras	Polygonum aviculare
Leek/ Onion/ Garlic	Look	Allium sp.
Legume family	Vlinderbloemenfamilie	Fabaceae
Lesser Bulrush	Kleine lisdodde	Typha angustifolia
Lime	Linde	Tilia sp.
Madder family	Sterbladigenfamilie	Rubiaceae

English	Nederlands	Scientific (Latin)
Marsh mallow	Echte heemst	Althaea officinalis
Meadowsweet	Moerasspirea	Filipendula ulmaria
Mint	Munt	Mentha-type
Mistletoe	Maretak	Viscum album
Mugwort	Alsem	Artemisia sp.
Mustard family	Kruisbloemenfamilie	Brassicaceae
Oak	Eik	Quercus sp.
Peat moss	Veenmos	Sphagnum
Pimpernel	Guichelheil	Anagallis-type
Pine	Den	Pinus sp.
Plantain	Weegbree	Plantago
Polypody	Eikvaren	Polypodium
Reed	Riet	Phragmites
Rose	Roos	Rosa sp.
Rose family	Rozenfamilie	Rosaceae
Royal fern	Koningsvaren	Osmunda regalis
Sedge family	Cypergrassenfamilie	Cyperaceae
Service tree	Lijsterbes	Sorbus sp.
Thrift/Sea lavender	Engels gras/Lamsoor	Armeria/Limonium
Water-plantain	Waterweegbree	Alisma sp.
White water-lily	Witte waterlelie	Nymphaea alba
Willow	Wilg	Salix sp.

Mammals and birds	Zoogdieren en vogels	Mammalia et volucres
Cattle	Rundvee	Bos
Dog	Hond	Canis
Duck	Eend	Anatidae
Perching birds/ Waders	Zangvogels/ Steltlopers	Passeriformes/ Charadriiformes
Red deer	Edelhert	Cervus elaphus
Ruminant	Herkauwer	Ruminantia
Scheep	Schaap	Ovis
Wild boar/ pig	Wild zwijn/ varken	Sus

Fish	Vissen	Piscatio
Pike	Snoek	Esox lucius
Perch	Baars	Perca fluviatilis
Cyprinid (carp) family	Karper familie	Cyprinidae

Helminths	Parasitaire wormen	
Helminth	Parasitaire worm	

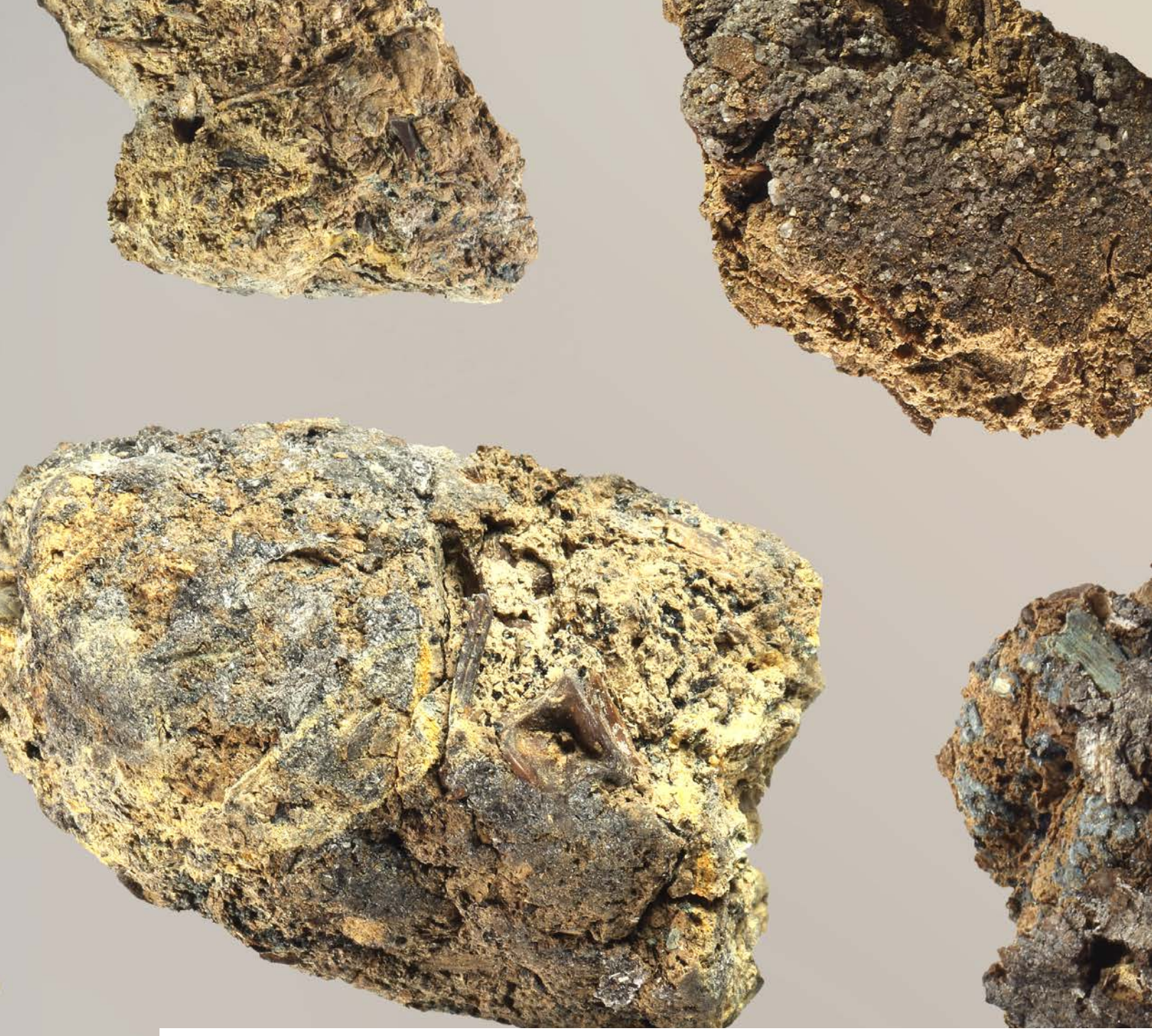
Intestinal roundworms	Rondwormen van de ingewanden	Intestinal nematodes
Whipworm	Zweepworm	Trichuris sp. (trichiura/ suis)

English	Nederlands	Scientific (Latin)
Hairworm	Haarworm	Capillaria sp.
Kidney worm	Nierworm	Dioctophyma sp.

Tapeworms	Lintwormen	Intestinal cestodes
Fish tapeworm	Vislintworm	Diphyllobothrium sp.
Fish tapeworm family	Vislintwormenfamilie	Diphyllobothriidae (trematoda)

Flukes	Zuigwormen	Trematoda
Lanceolate liver fluke family	Lanceolate leverbotten	Opisthorchiidae

Other roundworms	Overige rondwormen	Other Nematoda
Free-living nematode	Vrijlevende rondworm/aaltjes	(Free-living) Nematoda



This scientific report presents the results of the interdisciplinary study, which aimed to assess the diet and health of the Swifterbant Culture people through the analysis of coprolites from sites excavated before 2007. A group of specialists from universities and commercial companies worked together, using innovative research techniques, each contributing distinct datasets to the study. The project highlighted the dietary trends in food preparation in the Swifterbant culinary tradition. It also revealed a highly variable diet. At the Swifterbant sites, people were living together with their dogs (and pigs, nearby). They all shared the living space and likely had a similar diet as the people would have given the remains of their food preparations to the animals. This contribution can therefore be seen as the reconstruction of the Swifterbant community diet. This study also shows that the lifestyle and diet of the people and their animals resulted in intestinal parasite infections which affected their health.

This scientific report is intended for archaeologists, as well as for other professionals and amateur enthusiasts involved in archaeology.

The Cultural Heritage Agency provides knowledge and advice to give the future a past.